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ELECTRIC VEHICLE BATTERIES AS A NEW PARADIGM IN THE SUSTAINABLE DEVELOPMENT OF THE AUTOMOTIVE INDUSTRY

Relatore:

Chiar.ma Prof.ssa Antonella Zucchella

Tesi di Laurea
di Greta Caldarini

Matr. n. 501677

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“When the last tree is cut down, the last fish eaten,
and the last stream poisoned,
you will realise that you cannot eat money”
(Native American saying)

ABSTRACT

This thesis has the aim of investigating the critical role of electric vehicle batteries, chosen as the new pattern towards sustainable development in the automotive sector. The European Union has emerged as a leader in this movement, particularly through the European Green Deal, aiming at achieving climate neutrality by 2050.

After an analysis of the concept of global value chain, the text deepens the market of lithium-ion batteries, the most used type of power units in the automotive market nowadays, exploring all the stages of their global value chain from an economic and sustainability perspective, with an emphasis on the circular economy concept.

The central objective of this text is to highlight the enablers and barriers to sustainable development in the lithium-ion batteries global value chain and how the European Union is addressing its challenges through its policies and initiatives. Through qualitative research based on a multiple case study analysis, involving key industry players such as Albemarle Europe SRL, FREYR Battery Norway, Exide Technologies and DENIOS, it has been possible to propose future strategies from a European legislative and industrial point of view.

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ABBREVIATIONS

CO2: Carbon Dioxide

CRM: Critical Raw Materials

CRMA: Critical Raw Materials Act

DRG: Democratic Republic of Congo

EGC: Entreprise Général du Cobalt S.A

ESG: Environmental, Social, Governance

ESS: Energy Storage System

EU: European Union

EV: Electric Vehicle

EVB: Electric Vehicle Battery

GDP: Gross Domestic Product

GFC: Global Financial Crisis

GHG: Greenhouse Gases

GVC: Global Value Chain

GWh: Gigawatt hour

IRA: Inflation Reduction Act

IRMA: Initiative for Responsible Mining Assurance

JRC: Joint research centre

kWh: Kilowatt hour

LFP: Lithium Ferro Phosphate

LIB: lithium-ion battery

LMT: Light Means of Transport

OECD: Organisation for Economic Co-operation and Development

RMI: Raw Material Initiative

SLI: Starting Lighting Ignition

SWIFT: Society for Worldwide Interbank Financial Telecommunications

TFEU: Treaty on the Functioning of the European Union

USA: United States of America

UK: United Kingdom

VC: Value Chain

WTO: World Trade Organisation

INTRODUCTION

“We are the first generation to feel the impact of climate change and the last generation that can do something about it.” These are the words of an American governor reported by the ex-president of the United States of America, Barack Obama during his speech at the U.N Climate Change Summit, on 23rd September 2014 (Office of the Press Secretary, 2014). Almost ten years later these worlds are more relevant than ever, and the major international organisations are trying to find a solution to slow down the effects of climate change.

One of the major causes of this event is global warming. Greenhouse gases (GHG) emissions, mainly produced by means of transport, and fossil fuel usage, are responsible for this critical situation. In 2022, the global amount of emissions generated by the transport sector accounted for almost 8 billion metric tons (Tiseo, 2023).

In order to cope with this problem, the European Union decided to stake everything on the electric. Means of transport, electrically fuelled, are now the new frontier towards a greener world. In this perspective the European Union is leading the process through its initiatives and policies.

After the decisions taken during the Paris Agreement, the European Union created a project, the European Green Deal, made of a series of initiatives, whose aim is achieving climate neutrality within 2050 (Haas, 2020). 14th June 2023 marked a step forward for this result. After two years of revision, the European Commission approved the *Regulation (EU) 2023/1542 of the european parliament and of the council concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC*, commonly known as Batteries Regulation. This piece of law is not the first one which has been published in favour of the transition towards the electric, but it is the only one which focuses just on electric batteries. The aim of the European Union is to create a sustainable scenario which would not prevent future generations to suffer from their predecessors actions.

The EV market has grown and evolved along the years. This has been possible thanks to technology evolution and specific infrastructures, which have made these new sustainable means of transport more approachable. EVs seem to be the solution to the reduction of CO2 emissions. Even though their market is growing, it is strongly affected by the battery business.

The power units are a critical element of electric cars and the European Union is betting especially on LIBs (Razmjoo et al., 2022).

In the following chapters, after a brief explanation of the *global value chain* concept, where companies and countries' threats and opportunities, in being part of this integrated structure, are highlighted, the window closes and focuses on the LIBs GVC. The different steps of the GVC are analysed from an economical point of view and great attention is put on sustainability issues, as well as on the concept of circular economy. The aim of this thesis is to provide with more information in order to answer the research question: *what are the enablers and barriers to sustainable development in the global value chain of electric vehicle batteries, and how is the European Union addressing these challenges through its policies and initiatives*?
Being the topic a contemporary one, the study will be supported by a qualitative approach, based on multiple case study research, where companies point of view will be investigated. Thanks to interviews conducted with Albemarle Europe SRL, FREYR Battery Norway, Exide Technologies and DENIOS, through the application of the "sustainable development" concept, it has been possible to highlight those aspects which can contribute to greener development and those which prevent this objective to be achieved. According to this, some potential problems to be solved, and strategies to implement, from a European legislative point of view and from an industrial one, have been proposed.

CHAPTER 1
THE GLOBAL VALUE CHAIN

1.1 Definition and key aspects of the global value chain

The Global Value Chain (GVC) is the result of a more complex process called globalisation. This phenomenon is quite recent and it has changed the entire economic structure, creating a well integrated system and a high level of dependency among economies which became more and more specialised (Cattaneo, 2010; Gereffi, 2001). Firms compete in an international dimension, by receiving primary materials from abroad and selling their final outputs globally (Porter, 2011).

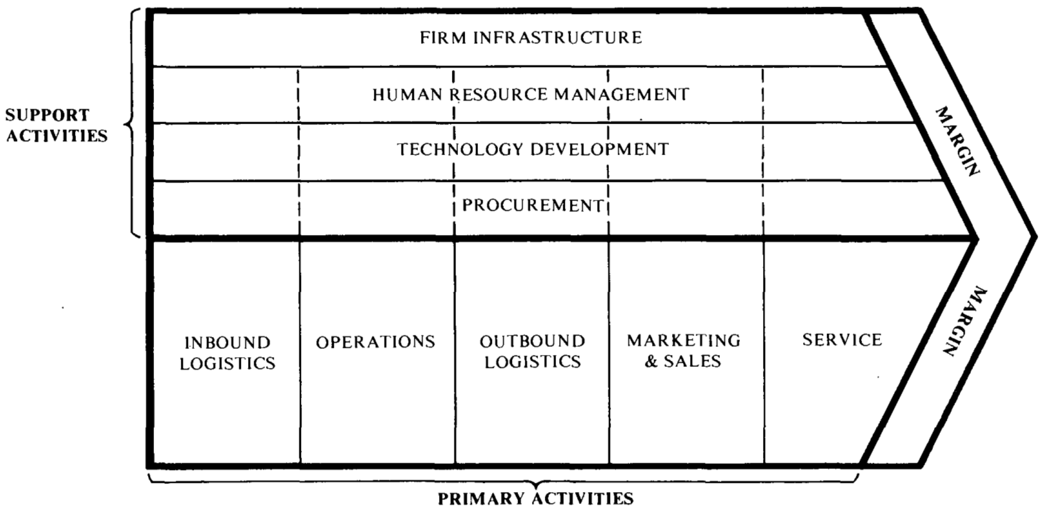
It is important to make a distinction between *globalisation* and *internationalisation*. The difference is really thin because both imply crossing national borders for economic activities but globalisation goes a step forward, activities are integrated even though distant from a geographical point of view.

In this context, thanks to Gary Gereffi, the concept of Global Value Chain rose. From this moment on, the attention is no longer focused on the production phase, the entire life cycle of the goods produced is taken into consideration and *governance* becomes a key aspect for the success (Gereffi, 2001).

The Global Value Chain is defined by Pol Antràs (2020) as "*a series of stages involved in producing a product or service that is sold to consumers, with each stage adding value, and with at least two stages being produced in different countries. A firm participates in a GVC if it produces at least one stage in a GVC*". There are two key points in this definition. The first one is the creation of *value added* by firms which take part in the process (Antràs, 2020). In a firm there are plenty of activities to accomplish, when they are performed, they generate value for the final user. The value is defined as the amount of money the final user is disposed to pay to buy the final good (Porter, 2011). The second one is the *conduction of firm activities in different parts of the world* (Antràs, 2020). This means that at least two components of a product are produced in foreign countries and then gathered and assembled together to ship the final good on the market. Nowadays, almost all the products which are sold on the market are "made in word" which means that all the production stages are not held in one country but delocalised in diverse realities (Miroudot, 2019).

According to Porter (2011), as shown in Figure 1, the value chain of a business is composed of different activities which can be divided into different groups. These activities are all interconnected and they are influenced by each other. They can be divided into *primary activities* and *support activities*. The first ones are the delivery of materials, the manufacturing, the distribution of the final product to the client, the selling and marketing activities and the service provided after the product has been sold. Each one of this activity is supported by the management of human resources, the use of technology, the procurement and all the infrastructures of the company. According to the business conducted, the firm will leverage more on one rather than on the other to achieve its competitive advantage on the market (Porter, 2011).

Figure 1: The Value Chain



Source: Porter, "Competitive advantage of nations: creating and sustaining superior performance", 2011.

The involvement in the GVC is not the same in all the parts of the world. Areas like Europe, North America and East Asia are more into this reality compared to countries from Africa or South America (Antràs, 2022; Miroudot, 2019; Simola, 2021).

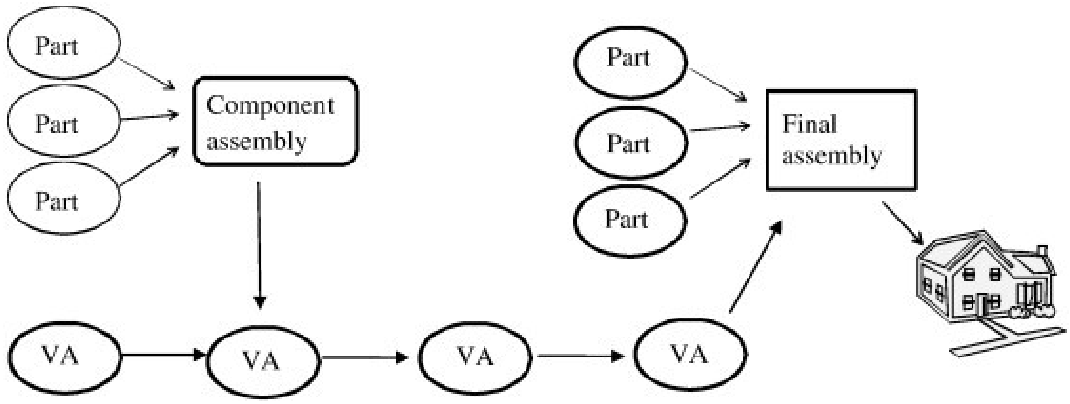
The way by which multinational companies operate on a global basis has changed over the years. This has been possible thanks to the reduction of economic restrictions and a deregulation policy which have opened the doors to the progress of information and communication technology. Even though the international activities conducted by firms do not have the traditional organisational structure and they are not unified from a geographical

point of view, the relationship that is created between the enterprises and its partners enables the creation of a more complex and interconnected system which permits the evolution of lead firms which operate internationally. As anticipated, this is also possible thanks to those mechanisms, rules and practices which regulate and coordinate the various actors involved in the GVC and which have at the same time a strong impact both on the macro and micro-environment (Kano, 2020). The governance power is exercised by those companies which have the strength to influence the activities of those businesses which are part of the value chain, mainly by controlling and providing them technical support (Kano, 2020; Gereffi, 2001). Governance structure usually originates from a need of leader firms to control the activities of their suppliers. Moreover, their influence will be more intense if the supplier's operational risk could have a direct impact on the lead firm. This has also a direct impact on the approach of companies situated in developing realities which want to internationalise (Gereffi, 2001). Sometimes, controlled decisions are not just influenced by lead firms but also by laws and institutions of those countries where economies operate (Kano, 2020). The organisational framework is a complex and dynamic process which seeks to balance the interests of various stakeholders, ensure compliance with standards and regulations, and facilitate efficient and sustainable global production networks (Kano, 2020; Gereffi, 2001).
All these have been possible thanks to the development of information technology which enabled the reduction of communication and transportation costs (Amador, 2016; Miroudot, 2019). Furthermore, transportations became faster and faster and more reliable. Geographical distance, which has always been represented a big obstacle, after this economic mutation and the evolution of the GVC has not been considered a problem anymore (Amador, 2016).

1.2 Structure of the GVC

According to some studies, the structure of the GVC can be represented in two different ways as shown by Figure 2. The first one has a *linear shape*, also known as *snake structure*. In this case the sequentiality of the different stages, which create value in the GVC is the key point and countries borders are crossed more than once. The second option, is the *convergent structure*, also defined as a *spider*, since the different elements to create the final good come together in one place and once it is ready, it is shipped and sold on the market (Antràs, 2022; Antràs, 2020). The GVC is characterised by the movement of inputs from one place to another. These inputs do not move just across countries but also within the production phases (Antràs, 2020).

Figure 2: Structure of the Global Value Chain



Source: Baldwin & Venables, "Spiders and snakes: Offshoring and agglomeration in the global economy", 2013

1.3 Analysis of the GVC

When companies decide to internationalise and, as a consequence, to participate in the GVC, they enter in contact with new possibilities and they create new relations with other entities but at the same time they face some difficulties, typical of operating in a global environment. In the following paragraphs, opportunities and threats of taking part in the GVC will be analysed.

1.3.1 Opportunities

International companies, which participate in the GVC, usually decide to offshore some stages of their production in less developed countries, since they can benefit from different advantages. The main reason why companies decide to offshore, usually is cost saving (Kedia, 2009). Labour costs are cheaper and raw materials can be bought at lower prices (Kedia, 2009; Antràs, 2020). Furthermore, companies tend to set up factories, responsible for different steps of the production line in foreign countries, since there, they can gain from trade and tariff concessions (Meixell, 2005). Institutions, indeed, can make the difference by setting specific requirements which can attract investments from abroad (Kano, 2020). As it is possible to notice, making use of an offshoring practice can lead companies to achieve great results on the market.

Moreover, the company can benefit from a high level of specialisation in specific activities abroad (Antràs, 2020). Participating in the GVC enables companies to enter in contact with new techniques and acquire new abilities and technologies. In case of partnership between the home and the host company, offshoring becomes a way to share knowledge and learn new capabilities which can generate economic growth and consequently a competitive advantage on the market (Manuj, 2008; Miroudot, 2019; Meixell, 2005; Gereffi, 2001, Kano,2020; Kedia, 2009). Great level of efficiency can indeed be achieved thanks to cost saving, better quality and higher competitiveness (Meixell, 2005). This type of organisation allows the business unit to be more flexible and react in a faster way to unexpected possibilities or menaces of the market (Kedia, 2009).

From a social point of view, participating in the GVC provides opportunities to have access to the global market, have direct contact with suppliers and create a more trustful relationship with them. Furthermore, it enables companies to expand their market presence and understand in a better way new customer segments needs, which can be served more quickly and efficiently (Meixell, 2005).

Another important aspect, which plays a crucial role in deciding whether offshoring an activity, is the host country's political and institutional stability (Antràs, 2020). Firms would never set up a business in high risk countries or in economies which are experiencing events like crisis or wars. These circumstances indeed, would generate an inefficient and dangerous environmental framework for the business activity conducted.

The trend of the GVC is shaped by the action of the State (Kano, 2020). Indeed, institutions' actions have an important position in determining the attraction of new business units in their countries. Let us think about the World Trade Organisation (WTO), created in 1995. It eliminated political and economic barriers, allowing economies to trade in a smoother way. From that moment the original value chain changed, making way for a more globally integrated structure (Miroudot, 2019). In addition, negotiations, treaties and trade agreements are a tool to enable smooth relations among the signing countries (Antràs, 2020).

The GVC is not just influenced by the environment but in turn it influences the macro-environment generating for example benefits for the less developed host country. Thanks to investments coming from abroad a phenomenon of migration within the nation can take place, reducing unemployment rate in specific areas thanks to the offer of new working opportunities, reducing as a consequence poverty phenomenon (Antràs, 2020; Kano, 2020).

These are all the reasons why multinational companies are evolving and organising their structure in relation to the GVC.

1.3.2 Threats

From one hand, as just mentioned, the GVC has positive aspects both for the companies which offshore their activities and for those countries which host enterprises, from the other hand some threats can be identified.

Due to the fact that production phases are not geographically close to each other, costs of transportation can be higher and delivery timing longer, compared to those activities carried out just in one country (Meixell, 2005). Furthermore, long geographic distances and shipment of goods which cross countries more than one time, generate a larger amount of CO_2 emissions which contribute to the environment pollution (Antràs, 2020).

Compared to the traditional value chain, where trade costs can increase the final price, in the GVC structure trade costs do not increase just the final price but also the costs that a company has to bear to buy the resources to create the ultimate product or service (Antràs, 2020).

Moreover, other factors which can be considered as a barrier for the efficiency of a company are the different cultures and languages, as well as different levels of experience and preparation of workers which operate in the business unit (Meixell, 2005).

Another important aspect which has to be taken into consideration, as mentioned before, is the instability of a country from the economical and political point of view (Meixell, 2005). This is a key element for a reliable and successful GVC, that's why governments which ensure this asset are more likely to rely on investments from foreign countries which allow them to take part in the GVC network organisation (Simola, 2021). A recent example is the war between Ukraine and Russia. When events like this happen there are consequences which affect the whole global economy, since all economies are interconnected. Countries which are directly involved in war suffer because they can not conduct their business as usual, they can not ensure the same efficiency, moreover, networks with other countries are usually damaged and they are often applied some financial restrictions. On the other hand, countries which rely on their economic actions have serious consequences. For instance, they do not receive products, or there are delays in delivery and prices of traded goods increase a lot. In this specific case Ukraine and Russia are big suppliers of elements like platinum, aluminium, steel and food and they are leaders in production of nickel, copper and iron. Even though they can not be compared to China, they have a big responsibility especially in the European market. When Russia decided to invade Ukraine, financial restrictions were applied to the country (Ngoc, 2022). Some economies cut air, land and sea connections with Russian companies, the US banned the import of gas and oil, whereas the European Union prohibited the export of all those technologies which helped Russia to refine oil (Balbaa, 2022). This was also supported by an action adopted by the EU, together with the US and UK, under the Ukrainian proposal (European Commission, 2022). 2nd March 2022, Russian banks were excluded from the SWIFT international payment system. This meant that from that moment on, Russian banks could not do international financial transactions efficiently and fast in all the world as before, generating distrust among its clients (European Commission, 2022; Ngoc, 2022). Economic and financial restrictions were not the only ones which were applied. People belonging to certain societal positions, who support the Russian President's actions, are still not allowed to enter and travel in the EU. Furthermore, Russian athletes were banned from participating as representatives of their country in international competitions (Balbaa, 2022).

As described, all the economic measures adopted against Russia had a big impact on the global economy. Certain products prices soared, the supply chain was modified since some countries were forced to search for suppliers of raw material in other countries, furthermore a big inflation took place and living costs increased a lot (Balbaa, 2022).

1.3.3 The effects of global events

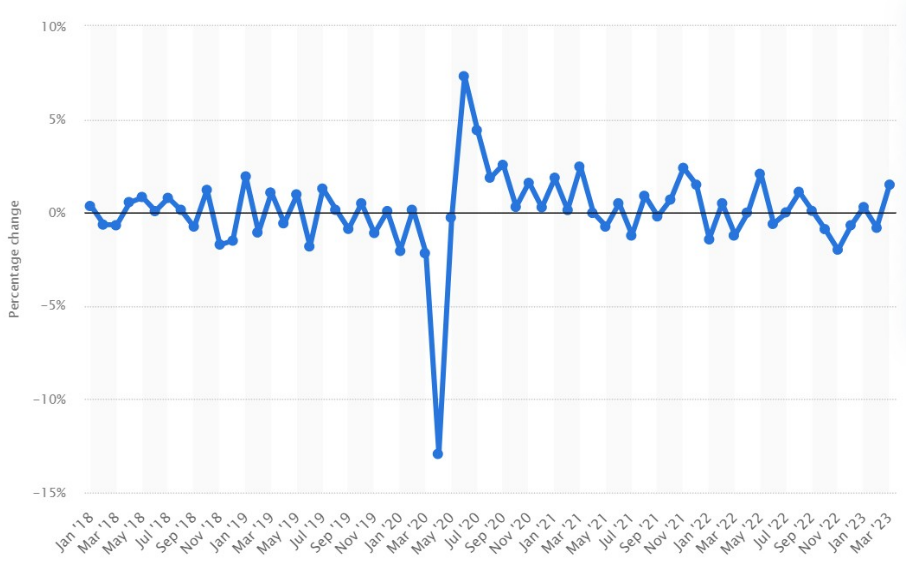
During the years, many events concurred to challenge the resilience of the GVC structure. Some of them have been temporary, which means that they have lasted for a limited period of time. They are for instance wars, global pandemic, crisis, international conflict or tensions among blocs or countries, global disasters etc. Others like the increasing protectionism policy, issues about sustainability, which take into consideration working labour conditions, environmental regulations, transportation and logistic environmental impact, etc., are considered structural, which means that they are more constant and long-lasting (Simola, 2021).

As already mentioned in the previous paragraph, geopolitical events like international wars and tensions have a strong impact on the GVC. Conflicts like the one between Ukraine and Russia, the ones in Afghanistan or Syria, can generate consequences from an economical and financial point of view, as well as on the social stratum. Indeed, trades and relationships with other countries are strongly affected by the circumstances the countries live in, furthermore, economic and financial sanctions are usually applied to those countries who take part in the conflict, since they can not assure stability from a financial and economical point of view. All these actions have visible effects in other parts of the world, different from the environment where the wars are taking place (Qin et al., 2023).

If analysing the other temporary events, like crisis, pandemic and environmental disasters, four facs and their respectively consequences are worthy to be mentioned: the Global Financial Crisis (GFC) in 2008, the Covid-19 pandemic and the earthquake in Japan and the Chao Phraya flood in Thailand in 2011. These circumstances caused respectively a collapse and a disruption of the GVC. In particular, the episodes in 2011 dramatically affected the automotive and computer industries. These events calmed down the expansion of the GVC and they led companies to diversify their network of suppliers in order to avoid possible future disasters.

The consequences of the Covid pandemic can be compared with those of the GFC. When the pandemic started in 2019, countries managed the situation without a common policy, even because they experienced different realities in diverse periods of time. So, changes which impacted a specific stage of the VC, had effects on the entire GVC. After the establishment of lockdown measures to try to contain the pandemic, the majority of companies stopped their production in 2020 (Simola, 2021). This generated a chain of consequences for the global economy. Furthermore, the number of people who died because of the virus, had a great impact on the global economic growth (Kano, 2020). As shown in the graph, during the first half of that year, global exports and imports in terms of volume and values hit a significant low, the global trade volume registered a decrease of 12.9% (Statista research department, 2023).

Figure 3: Change in global goods trade volume from January 2018 to April 2023



Source: Statista research department, "Change in global goods trade volume from January 2018 to April 2023", July 2023.

The pandemic gave birth to some ideologies against the evolution of the GVC. Indeed, when the first economy in the world, China, started to close its factories, it generated a domino effect on the world's economy. Some countries, whose main supplier was China, faced difficulties in carrying on their activities, since they did not stop their production and faced problems in finding inputs from abroad (Hayakawa, 2021; Simola, 2021).

Logistic was interrupted, products started to run out and costs of transportation soared (Ngoc, 2022), for this reason, some of the businesses who needed for raw materials started to search for new providers in other countries, or searching for inputs in the domestic market, in order to avoid possible problems related to delay in delivery materials, which would have led to a decrease in the production (Hayakawa, 2021).

Even though economic and social consequences left visible signs in the global economic history, actual outcomes were not worse than those of the GFC in 2008. Indeed, if from one side the GVC structure is the reason why bad events, which happen in one country, have negative consequences in other parts of the world, it is also true that the global integrated structure of the GVC helps companies to survive these catastrophic episodes. During the Covid pandemic, some sectors were affected more than others, for instance transports, fuel and mineral products, whereas the sanitary market increased rapidly due to the high demand

of medicines in that period. Without this type of organisation, the consequences would probably have been worse (Simola, 2021; Jackson, 2021).
Situations like these enabled the spread of the *protectionism ideal* across the world economy. Protectionism was born in response to globalisation in order to defend national production from the international threats and create job opportunities in the country (Simola, 2021). In the years, it mainly emerged during crisis periods, in response to instability on the financial market or increased costs or just for strategic choices (Kano, 2020). Usually measures, which are taken to implement it, are trade barriers, like non-tariff barriers (Simola, 2021, Miroudot, 2019). They reduce competitiveness on the market and at the same time they generate losses in terms of wellbeing (Simola, 2021).
This type of action is easier to implement for developed economies, since they have more resources both in terms of money to invest in new technologies and in terms of suppliers and consumers number (Simola, 2021; Kano, 2020).
Sustainability issues are other fundamental aspects which have relevant effects on the GVC structure. Sustainability is considered from an environmental, social and economical point of view. According to these features, criteria are established by firms, in order to conduct a sustainable business. Hence, being part of the GVC means being able to apply those standards which allow the creation of sustainable goods (Manning et al., 2012). Companies are becoming more and more aware of problems like *working conditions* and *child labour exploitation* since they have a strong impact on the brand reputation, not just from a customer point of view but also from other companies points of view. This can indeed affect relationships with other businesses, the final outcomes and sales volumes. For this reason, companies are applying international norms and standards in order to avoid these issues (Pegler & Knorringa, 2007).
The last sustainability aspect, which is worthy to be mentioned, is the logistic *environmental impact*. With the development of globalisation, the different stages of goods production have been delocalised in different parts of the world. If from one side this practice enabled companies to save money, from the other side, it implied the continuing movement of intermediate products from one part of the world to another and as a consequence the increasing level of greenhouse gases emissions. This generates a greater environmental impact which could be avoided by conducting all the production phases in the place where the final goods are sold. In this way, for a company, it is more difficult to reach the eventually

required international targets in terms of emissions. For this reason, there are companies which try to reduce their emissions by making use of practices like planting trees (Gifford, 2019; Miroudot, 2019).

As a result of all these factors which affect the GVC, as explained by Simola (2021), the shortening of the GVC, from a *regional value chain* perspective, is becoming a more viable approach. It enables companies to be less exposed to global shocks. This is supported by the increasing *reshoring policy*. Companies are reimporting some of their activities conducted abroad, in their home country to ensure availability of materials, stability to their VC structure and minimise issues related to dependency on other economies.

If from one side global events emphasised the overreliance among economies making reshoring and protectionism seem to be the best solutions. From the other side they proved that these policies are not the best option when it comes to global shocks and that the actual GVC organisation network helped many economies not to collapse during these events (Simola, 2021).

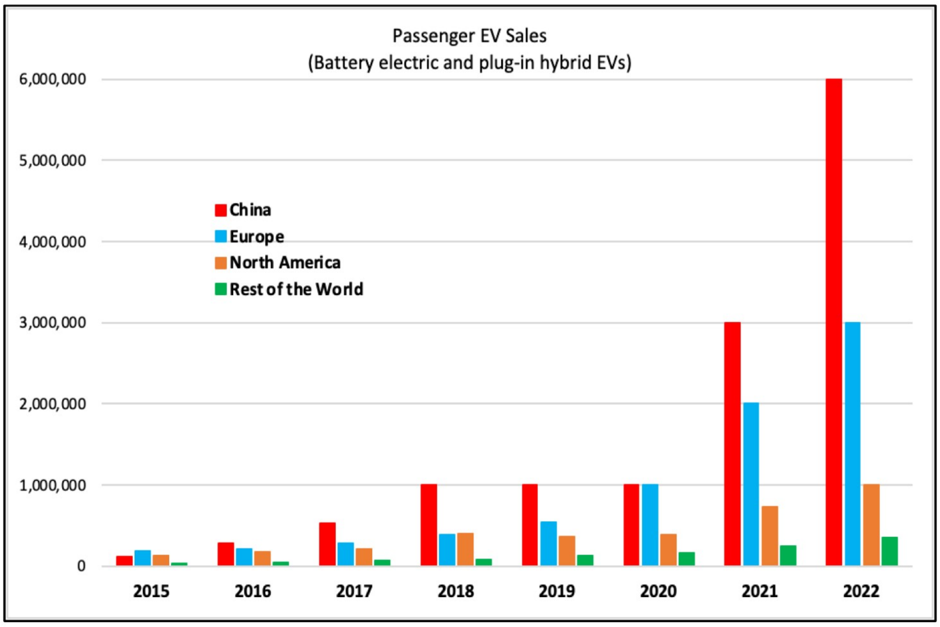
CHAPTER 2
GLOBAL VALUE CHAIN OF ELECTRIC VEHICLE LITHIUM-ION BATTERIES

2.1 Electric cars as new paradigm in the automotive industry

Recently the automotive sector is experiencing a shift towards electric. The aim is to reduce the amount of CO2 emitted by means of transport in order to slow down global warming, the main cause of climate change. This evolution is a complex process, which gives special attention to sustainability issues and in this field the European Union is probably the leading organisation.

The number of electric vehicles sold globally have increased along the last decades. Just in 2019, during the covid pandemic, sales registered a drop down because of the stop of the global economy. Despite this, the recovery was not long in coming. Just in one year sales soared by 100% reaching 6.6 million globally in 2021. Half of them were sold just in China, which is nowadays the biggest market in the world, followed by Europe and USA. This soaring has been possible also thanks to the government's policy which gave incentives to buy new EVs, built more and more innovative charging stations to boost the development of the market and encouraged innovation from a technological point of view. China is an example. As shown in figure 4, the amount of electric cars sold in 2022 doubled compared to the previous year (Razmjoo et al., 2022).

Figure 4: Passenger electric vehicle sales form 2015 to 2022



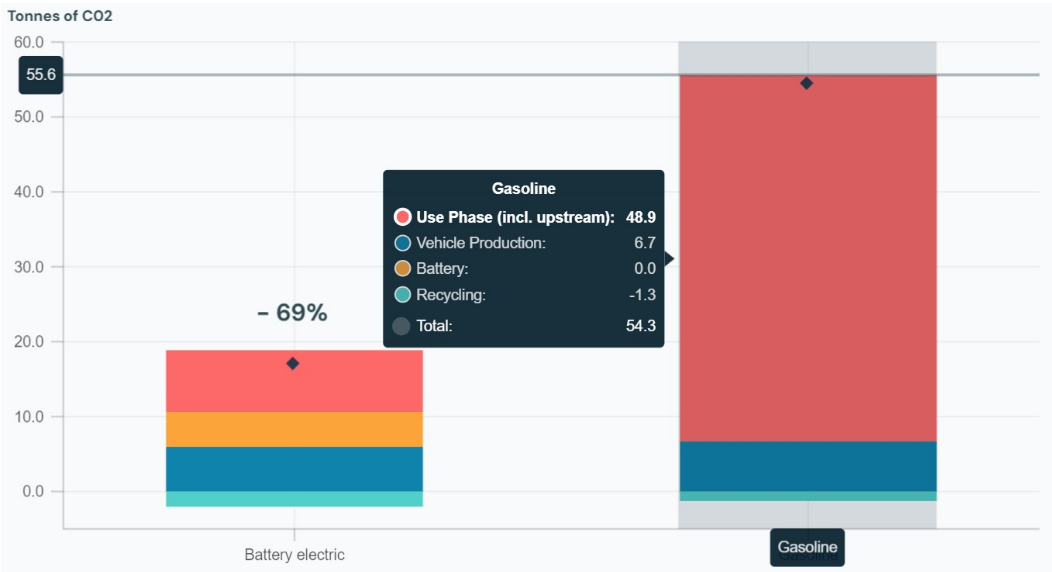
Source: Razmjoo et al., "A Comprehensive Study on the Expansion of Electric Vehicles in Europe", 2022.

A positive aspect which can be obtained by introducing electric cars in our society is for instance the reduction of gasoline use, which contributes to decreasing levels of greenhouse gases emitted, which are one of the main reasons for the pollution of the environment. This will contribute to the achievement of the objectives for a greener world. Another important aspect which is worthy to be mentioned is the fact that cars powered by electric motors have less components and as a consequence the probability to suffer a damage is lower then the one of a fossil fuelled one (Razmjoo et al., 2022).

Substituting petrol cars with electric cars means cutting by ⅓ CO_2 emissions. A medium electric vehicle, produced, sold and used in the EU, creates on average 75g of CO_2 emissions per Km, whereas a petrol car 241g. The difference is really huge and even though in the production phase the CO_2 produced by an electric car is higher compared to the fuel one, in the long term the result tips over. Indeed, if we analyse the tons of CO_2 emitted in the different stages of a vehicle life, as shown in figure 5, it is possible to notice that in the production phase emissions are almost the same, both for the EV and for the gasoline one, the EV registers a higher level of emission in terms of battery realisation which is not taken into consideration for the fuel car. The real difference in terms of emissions is evident in the usage phase. At this stage the electric car emits an amount of carbon dioxide which is almost six

times less than the gasoline fuelled car, reporting a considerably lower amount of CO2 emitted on the overall stages. It has been predicted that within 2030 EV produced will reduce even more their emissions (Gimbert, 2022).
While using an electric car, levels of dioxide released in the environment should be null. Actually, if we look at figure 5 a certain amount of CO2 emitted during that stage is still present. This is because the calculation is made on the emissions generated by the electricity, produced to recharge the EVs, which does not originate from renewable resources. Even though levels of dioxide emitted by EVs are really low compared to non-electric cars, the usage of fossil fuels generated electricity to recharge them is slowing down the achievement of the zero emission goal in the transport sector, which could have effects also on climate change. Therefore, the reliance on renewable energy could lead to the achievement of important outcomes (Rajaeifar et al., 2022).

Figure 5: Comparison between EVs and gasoline fuel cars in terms of tonnes of CO2 emitted



Source: Gimbert, "How clean are electric cars?", May 2022.

There are of course different aspects which have to be taken into consideration when calculating the emissions a vehicle produces. For example the geographical position where the components are realised and the country where the EV is sold and used, have an impact on the total amount of CO2 emitted. For instance an electric car which is made in China and then shipped in the EU will count more carbon dioxide diffused than an EV produced and used in the same nation, since the transportation of the materials contributes to increase levels of CO2 emitted. Another important factor is the impact of the electricity production to recharge the car. A country like Poland which uses a great amount of carbon to generate electricity will have a stronger impact compared to a country like Sweden which is shifting its electricity production towards a net zero carbon emission policy relying on renewable resources (*T&E's analysis of electric car lifecycle* CO_2 *emissions,* 2020, p.12).

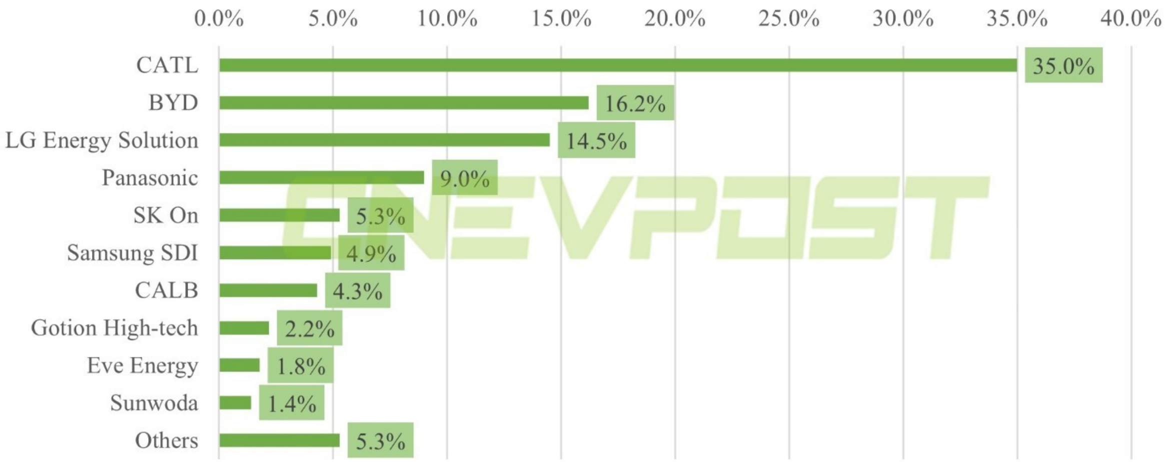
Nowadays, it has been observed that even though an electric car is more expensive than a diesel or fossil fuel one, it is cheaper to own it because of the lower cost of maintenance. This has become even more evident after the rise of the fuel prices in 2022, indeed on the overall costs of a conventional car, 28% are attributable to refuelling, a higher percentage compared to the 15% of an electric car (Campbell, 2022).

2.1.1 Main manufacturers of electric vehicle batteries

As just mentioned the electric vehicle market is growing and as a consequence also the battery market is increasing quite rapidly. The most common electric vehicle batteries (EVBs) used on the market are lithium-ion batteries (Rajaeifar et al., 2022; Scott & Ireland, 2020). They can have different shapes like cylindrical, pouch and prismatic (Halimah et al., 2019) and thanks to their composition they are preferred to other types of power units because of their efficiency in gathering a greater quantity of energy that can be used when necessary (Halimah et al., 2019; Rajaeifar et al., 2022; Scott & Ireland, 2020).

When considering the market share of 2023 first trimester, the main producers of LIBs are the following companies: CATL (Contemporary Amperex Technology Co.), with a market share of 35%, BYD Company 16.2% of market share, LG Energy Solution, Ltd., which ranks third with 14.5%, Panasonic Holding Corporation, with 9%, and SK Innovation Co., Ltd. which accounts for 5.3% (Kang, 2023).

Figure 6: Market share of world's top EV battery makers (Jan-Feb 2023)



Source: Kang, "Global EV battery market share in Q1: CATL 35%, BYD 16.2%", May 2023.

CATL is a Chinese company which has been leading the market of battery manufacturers in the last few years. It provides batteries to the biggest producers of EV like Hyundai, Honda, BMW, Tesla, Toyota, Volkswagen… Its position is due to relatively low costs of production, technological advancement and stability in its capital market (Farooq, 2023). In 2021 the company could count on five working megafactory and six in construction (Moores, 2021).

On the 16th of August 2022, the president of the USA, Joe Biden, signed the *Inflation Reduction Act* (IRA), a piece of legislation whose aim was to contain the US inflation by taking different actions in different sectors and supporting the domestic industry. In the battery landscape, it was imposed on EVs producers to manufacture their goods without relying on component provision coming from China, if they wanted to get financial aid. The idea of the USA government was to reduce the dependency they had from China, especially in this sector. As a consequence, this measure had big effects on the global value chain of EVs. Japanese and South Korean companies benefited from this, but at the same time Chinese businesses were forced to find solutions to continue their economic relationship with American clients. This is the reason why CATL could not do joint ventures with local companies. In order to actuate in the USA, it decided to make a deal with Ford instead. They stipulated to build a factory in the USA where Ford will have the right to use the Chinese technology to develop its products. In this way the goods produced will be home made and they could comply with the IRA law. The new factory is valued $35 billion. Unfortunately, this trick has not been appreciated by the highest offices which are trying to stop this plan with some additive measures (Davies, 2023).

Thanks to its multiple clients like Nio, XPeng and LiAuto in China, in 2022, CATL represented almost ⅓ of the EV batteries sold in the world (Li, 2023).

For Korean companies, like LG Energy Solution, Ltd. and SK Innovation Co., Ltd., relationships with the USA seem to be easier. Indeed, they started joint ventures with local companies, in order to supply the US market. LG Energy Solution for instance, collaborates in the USA with General Motors and Stellantis. Furthermore, it is working on a new partnership with Honda (Davies, 2023a). Whereas, SK Innovation Co., Ltd. discussed a $5 billion project with Hyundai to implement a battery factory in the States (Davies, 2023). Also Panasonic Holding Corporation, which has a strong bond with Tesla, at the end of 2022, started to work on a $4 billion project, in the centre of the USA. It also cooperates with brands like Toyota and Lucid Group (Farooq, 2023).

BYD, direct competitor of CATL and second producer of EVBs for market share, was one of the first companies in converting its production to implement a more sustainable industry (Riordan et al., 2022). In 2021, it was classified as the second manufacturer of lithium-ion cells in China (Farooq, 2023). The company produces both batteries and electric vehicles, in this way it can supply itself without depending on other companies (Kang, 2023).

Unfortunately, in 2022 the company was involved in a social issue. Indeed, citizens coming from the areas where the company has its factories, started to report physical illnesses because of the emission caused by the toxic paints used to paint cars, which release harmful substances for human beings. The spotlight went on when one of the workers of BYD suffered a stroke some months after he quit the job, probably because of the inhalation he had during his working period (Riordan et al., 2022).

In the European landscape, a Swedish company, Northvolt, made the difference. In December 2021, it created the first battery produced in a gigafactory in Europe. The manufacturing process used just renewable energy. Indeed the aim of the company is to generate batteries in the most sustainable way. This step marked the starting point of a more complex project which has the objective to produce an amount of gigawatt hour (GWh) per year such that they could supply 1 million of EVs. Furthermore, they would like to establish two other gigafactories in Europe to improve the amount of GWh produced and they are collaborating with Volvo in the realisation of a third one (Milne, 2021).

The presence of a gigafactory in Sweden had effects also on the social stratum of those areas. New working positions have been created and up to 3,000 employees are expected to be hired in the next few years (Milne, 2021).

2.2 Global Value Chain of LIBs

EXXON, in the USA, was the first company in the 70s in creating the first model of lithium-ion batteries. After almost twenty years, in 1991, the global giant Sony sold this new technology on the market (Scott & Ireland, 2020). Nowadays, we can find lithium-ion batteries in different devices like smartphones and laptops. In the last few years, they have become the most common electric vehicle batteries used on the market (Rajaeifar et al., 2022; Scott & Ireland, 2020).

Thanks to the implementation of electric vehicles battery powered, the emissions of CO2 could reduce significantly (Campagnol et al., 2022; Scott & Ireland, 2020), indeed the amount of carbon dioxide released by an electric car is one sixth less compared to the one emitted by a fossil fuelled one (Gimbert, 2022).

The GVC of the lithium-ion batteries is composed of six main steps, which will be analysed in detail in the next paragraphs: the extraction of raw materials, the processing, the production of the battery, the usage, the end of life and the recycling or reuse (LaRocca, 2020).

The materials used to manufacture lithium-ion batteries are multiple and complex to obtain. They are both metals and nonmetals and the majority of them are extracted in different parts of the world. As explained in the previous paragraph each stage of the value chain is strictly connected to all the others. In this specific case, LIBs production is influenced by its raw material supply chain (Rajaeifar et al., 2022). In this thesis, lithium, cobalt and graphite markets will be analysed. In particular, the focus will be on reserves of lithium present in Australia and South America, respectively in the form of mines and brines (LaRocca, 2020; Palandrani, 2020a; Scott & Ireland, 2020). Its extraction has strong consequences from an environmental point of view, indeed the amount of water required to obtain lithium could affect the water local reserves (Rajaeifar et al., 2022).

The biggest supplier of extracted cobalt is the Democratic Republic of Congo (DRG) (Deberdt, 2021; Savinova et al., 2023). In this market some concerns have been raised because of the general condition at which this process is conducted in the country. Indeed, issues like minor work exploitation and not favourable working conditions have been taken into consideration (Calvão et al., 2021; Deberdt, 2023). Furthermore, Chinese companies own the majority of the operating mines in the country, this could generate negative consequences. For instance, in case of scarcity of cobalt on the market, because of political or social issues this company would provide material to Chinese producers, creating the disruption of the global supply chain (Rajaeifar et al., 2022).

The last element, graphite, is extracted in China, even though the biggest reserve, not yet exploited, is located in Turkey (Garside, 2023a; Scott & Ireland, 2020; Tsuji, 2022).

It is possible to pre-announce that the extraction and refining stage, as well as the production of electric batteries are led by China, which has a strong competitive advantage in all the GVC EVBs phases. This is possible thanks to its efficiency, its availability of important financial resources and to the fact that China has been one of the first in the market to have put in practice these processes (Gifford, 2019).

Among the best companies which operate in the extraction sector, the majority of them are from China, this is evident especially in the graphite market where over the five best businesses, four of them are Chinese (Kumar et al., 2021; LaRocca, 2020; La Monica et al., 2020; Matthews, 2020).

Due to the increasing demand of EVs, the quantity of raw materials required to manufacture batteries is soaring, overcoming the actual supply capacity (Palandrani, 2020a; Sommerville et al., 2021). Materials like lithium, cobalt and graphite, which are essential elements for the creation of lithium-ion batteries, are defined as critical materials, since their availability in the future is connected to the critical use made of them in these years (Critical Raw material Act, 2023).

Once these materials are extracted, they need to be refined in order to obtain substances which can be used to generate batteries. This process, as already anticipated, is mainly conducted by Chinese companies which, in the majority of the cases, ship the extracted products in their country to refine them (LaRocca, 2020). It is an exception the DRC, where as a consequence of some economical and political issues, some Chinese companies decided to build refineries close to their mines and conduct both processes in the country, exporting the already purified materials (Matthews, 2020). As it is possible to notice from what just presented, the different procedures can be carried out in different areas of the world, or all in the same site. Hence, in

some cases the same company which is in charge of the extraction, takes care of the refining process as well (Coffin & Horowitz, 2018).
The refined materials are then used to produce batteries which will be integrated in the electric vehicles. LIBs manufacturing market is led by the Asian continent and especially by countries like China, Japan and South Korea (Carrara et a., 2023; Coffin & Horowitz, 2018; Scott & Ireland, 2020). Batteries are produced in gigafactories which are battery cell plants. These places have a huge surface and they have strong impacts on the society and the environment where they are located. Its presence has effects on the local communities GDP. Due to the increasing demand of EVs in the near future, it has been estimated that the battery cell market will register an increase of around 20% annually in the next seven years, attaining $360 billion worldwide. This big growth will ask for more capacity which will be translated into the realisation of new gigafactories. Young markets like Europe and the United States, which are expected to reach high demand for electric cars, could be the right places to implement these new infrastructures (Campagnol et al., 2022). Nowadays, the most important manufacturer of LIBs is the Chinese company CATL, with a total capacity of more than 100 GWh (Moores, 2021). Even though more and more people are buying EVs, the amount of private electric cars globally is still represented by a small percentage compared to the fossil fuelled ones, and China is an important part of it (Scott & Ireland, 2020). In 2022, EVs sold in the country have been 27 million compared to slightly more than 13 million in the USA and just less than 10 million in the European Union (Ravaldini, 2023). The scepticism in buying EVs can be justified by the lack of charging stations especially in minor residential zones, the fear of short autonomy of the power unit (Jussani et al., 2017) and the high prices of the vehicles present on the market (Halimah et al., 2019; Scott & Ireland, 2020).
Indeed in 2022, due to the scarcity of metals used to manufacture batteries, their prices soared and as a consequence also batteries and EVs prices increased (Dempsey, 2022a).
Despite this the battery market is expected to grow in the next few years (Gifford, 2019), hence in order to regulate this market and to find a common line of action, the European Union is working on this topic. In 2023, two important pieces of legislation have been approved: the Regulation of the european parliament and of the council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, Regulation n. COM 160/2023, known as Critical Raw Material Act and the Regulation (EU)

2023/1542 of the european parliament and of the council concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, known as the Batteries Regulation. The first one focuses on the criticality of the raw materials used to manufacture batteries and its aim is to find solutions to problems like the supply chain disruption, instability of prices and dependency from external suppliers promoting responsible and sustainable actions. The second piece of legislation is a product specific legislation whose subject is batteries. It studies their entire life cycle by promoting the efficiency of their internal market with special attention to the environmental and human health impact and management of wasted batteries.

Waste management is the last and crucial stage of the battery value chain. To cope with the upcoming issues related to lack of raw material and relatively high prices, some possible solutions have been studied. The best results are the second usage and the recycling of the power unit. In the first case when a car battery reaches the disposal stage but still has the characteristics to be used, it is taken from the vehicle and implemented for instance in an energy storage system (ESS). In the recycling option, the aim is to recuperate those possible elements, which are essential for the realisation of a new power unit. In this case the procedure is more delicate and it has to be treated carefully, since LIBs structure is quite complex to handle. This process is not well developed yet, since it is at its beginning. Moreover, it can be conducted in different locations from the one where batteries are removed from the vehicles, which means shipping disposed LIBs in different parts of the world (Melin, 2018; Rajaeifar et al., 2022; Sommerville et al., 2020).

Through the recycling action, the raw material global supply market can be relieved by the great amount of goods asked to manufacture the final product (Sommerville et al., 2021).

Thanks to these procedures, which are becoming essential for the transition towards the electric, the LIBs life cycle has become circular. Furthermore, the implementation of the second use before the recycling stage, enables to make the LIBs lifecycle even longer, delaying the disposal stage.

2.2.1 Extraction and processing of raw materials

The extraction of raw materials is the first stage of the LIBs GVC. The main components of LIBs are lithium, cobalt, nickel and graphite. Among them only graphite is non-metal (LaRocca, 2020; Scott & Ireland, 2020). These elements are mined in different parts of the world and processed in order to obtain materials that can be used to create batteries. We are now focusing on each element and highlighting the main important features.

2.2.1.1 Lithium

Lithium and cobalt are present in LIBs with almost the same percentage and nowadays there are no elements which could substitute lithium in LIBs (LaRocca, 2020). Compared to hybrid vehicles, laptops, tablets and mobile phones, electric vehicles are those where the largest amount of lithium is used. Indeed lithium-ions are more efficient, long-lasting and less heavy than other possible substitutes, making vehicles more performing (Palandrani, 2020a, Kumar et al., 2021). This is the reason why the lithium market will be strongly affected by the increasing demand of the electric car market (Palandrani, 2020a). These effects are already evident, from 2016 and 2018 lithium production registered an increase of 98% (Tabelin et al., 2021).

Lithium is present in many countries but just few of them have enough reserves to satisfy the global demand (LaRocca, 2020). The almost total amount of lithium resources are concentrated just in the Americas, especially in Bolivia, Chile, Argentina (Jussani et al., 2017) and in the United States, Australia and China where it is also possible to find big reserves of Cobalt (Kumar et al., 2021; Palandrani, 2020a). As a consequence these countries are responsible for the provision and production of LIBs globally (Kumar et al., 2021). For instance Australia, in 2019, was responsible for 54% of the global lithium production (Tabelin et al., 2021), whereas resources coming from Argentina, Bolivia and Chile, which are dubbed Lithium Triangle, in the same year, accounted for 59% of the identified resources worldwide (Palandrani, 2020b, Tabelin et al., 2021).

Lithium exists in nature but it has to be processed in order to obtain a more concentrated combination which could be used to produce LIBs (LaRocca, 2020). There are two sources through which lithium can be obtained, mining extraction, mainly in Australia and salty water extraction, in South America (LaRocca, 2020; Palandrani, 2020a; Scott & Ireland, 2020). Lithium used in EVBs comes from both types of deposit, even though the one deriving from mining extraction has higher costs compared to the one obtained from brine, since it requires more accurate actions (Palandrani, 2020a).

Companies which extract unprocessed lithium are not a lot and they are characterised by partnerships with business units which operate in their same sector. The most important are

Albemarle, SQM (Sociedad Química y Minera de Chile), Ganfeng Lithium Co., Tianqi Lithium and Mineral Resources (Barrera & Kelly, 2023; LaRocca, 2020; La Monica et al., 2020; Palandrani, 2020b).

Albemarle and SQM with a market cap of US$ 25.65 billion and US$ 20.67 billion respectively in 2023, operate mostly in brines in Chile (Barrera & Kelly, 2023; LaRocca, 2020; La Monica et al., 2020). In 2019, they together produced 75,000 tons of lithium carbonate (Tabelin et al., 2021). Albemarle, an US company, is the biggest extractor in the world. It has a heavy presence also in Australia thanks to its participation in Greenbushes open-pit mine, the most extended hard-rock worldwide, with an ownership of 49% stake. Also SQM, thanks to a joint venture, is developing its business in the Mount Holland project in Western Australia (Barrera & Kelly, 2023). In Australia there are seven Lithium mines in action: Greenbushes, Wodgina, Mount Marion, Mount Cattlin, Bald hill, Pilgangoora and Finniss (Tabelin et al., 2021).

The third company in terms of market cap, US$ 18.37 billion, Ganfeng Lithium Co., followed by Tanqui Lithium US$ 17.49 billion and Mineral Resources US$ 9.86 billion, is a Chinese company which has its main production in Western Australia, particularly in Mount Marion hard-rock mine, where it shares a joint venture with MinRes, as well as in Mexico, Mali and Argentina. It supplies important companies like Tesla, Panasonic, LG Chem, BMW and Volkswagen (Barrera & Kelly, 2023; Palandrani, 2020b).

In Europe there are minor mines, for instance in Portugal, Czech Republic and Serbia (La Monica et al., 2020). At the beginning of 2023, LKAB, a Swedish mining company, announced the discovery of the biggest mine of rare earths in Europe. It is situated in the Kiruna region, in Sweden. Even though the dimensions of the mine are not exactly known, the amount of materials present accounts for around 1 million tons. The European Union is trying to speed up the processes in order to ease the dependence of the foreign suppliers, but it has been estimated that it will take more than ten years to extract and sell the product on the market (Fleming, 2023; Gotev, 2023).

Unlike other materials, like cobalt, which will be analysed in the following paragraph, lithium extraction has a stable situation from a political point of view (Scott & Ireland, 2020)

After lithium is extracted it has to be processed in order to be used to produce EVBs. Through refining, two types of processed lithium chemicals are obtained, the lithium carbonate and lithium hydroxide. They are used to create parts of the cathode and electrolyte (LaRocca, 2020; La Monica et al., 2020).

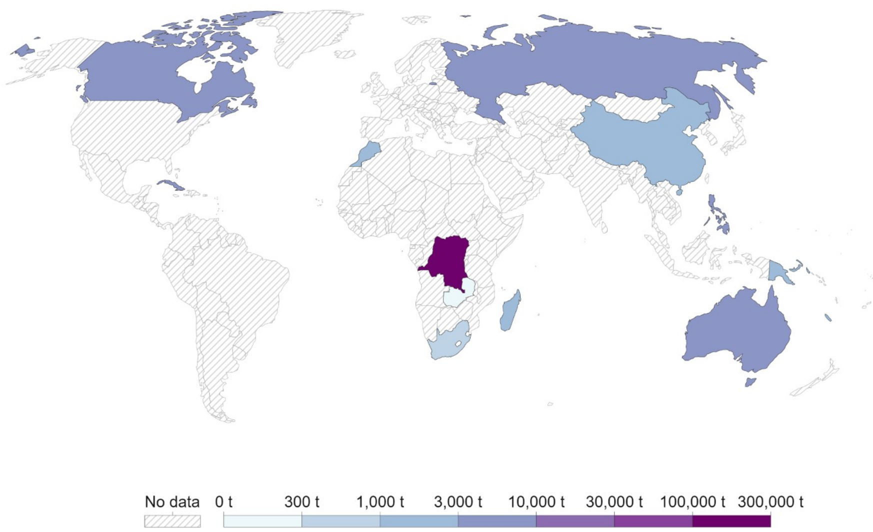
At this stage China is the leading player. It receives and refines unprocessed lithium extracted in Australia, the predominant exporter, and in Chile. Japan and South Korea help China in this operation but they have a marginal role (LaRocca, 2020).

2.2.1.2 Cobalt

According to the different typologies of EVBs, refined cobalt is an important element since it resists elevated temperatures and corrosion, which makes batteries' lifetime lasting more. Moreover, thanks to its composition, it enables the battery to accumulate and transfer a big amount of energy (Matthews, 2020; Scott & Ireland, 2020). In order to create an EVB 10/15 kg of cobalt are needed (Calvão et al., 2021). More than half of the worldwide demand for cobalt comes from the battery industry and its global production has soared dramatically in less than forty years (Savinova et al., 2023).

Cobalt is extracted and refined from deposits of nickel and copper which, as shown by figure 7, are mainly present in the DRC, Russia, Canada, Cuba, Australia and Philippines.

Figure 7: Worldwide cobalt production in 2022



Source: Our World in Data, Cobalt production, 2022.

This makes cobalt strongly dependent on these two markets (La Monica et al., 2020; Matthews, 2020; Kumar et al., 2021). It has been estimated that, last year, the worldwide funds of cobalt accounted for 7.6 million tons (Savinova et al., 2023).
Even though the largest supplier of unrefined cobalt is DRC, with 71% of the global production and more than 40% of worldwide reserves (Deberdt, 2021; Savinova et al., 2023), China has a position of predominance in all the entire working process (La Monica et al., 2020; Kumar et al., 2021, Matthews, 2020). Out of 18 active cobalt deposits, 10 are owned by China giving it the power on half of the total amount of cobalt reserves (Kumar et al., 2021).
In the extraction stage, according to the revenues of 2021, since some of them not still available for 2022, the most important companies are Glencore PLC ($203.8 billion revenue), China Molybdenum International (CMOC) ($24.1 billion revenue), Eurasian Resources Group ($33 billion revenue), Gécamines ($33.69 billion revenue) and Vale S.A. ($54.5 billion revenue) (Muroki, 2022).
The total amount of Cobalt produced by Glencore PLC in 2022 was 43,8 thousand metric tons (Garside, 2023), more than ten thousand metric tons than the previous year. It has mines in Katanga and Mutanda in the DRC, as well as some in Canada, Australia and Norway. In 2021 Mashamba East reserve, in Katanga, was responsible for more than 50% of the total amount of cobalt produced by the company (Muroki, 2022).
Vale S.A works in South America and Canada (Muroki, 2022). Even though it is one of the most important companies for cobalt production, it reached its high in 2017 with 5,811 thousand metric tons of cobalt produced but then the production fell gradually till 2,434 thousand metric tons in 2022, however conserving its position of predominance in the market (Garside, 2023b).
Gécamines, the third biggest mining company in terms of revenue, acts mainly in the DRC. It is also a stakeholder of Glencore, Eurasian Resources Group and China Molybdenum and in 2021 it generated 13,860 tons of cobalt (Muroki, 2022).
Cobalt production didn't report a linear increasing trend, over the past few years. Some setbacks due to political, social and financial events have been registered. They were evident during the global financial crisis in 2008, the two wars of Congo and the period in which the cobalt extraction sector was not regulated by any formal law (Savinova et al., 2023).
The Commission Delegated Regulation (EU) 2023/410, from 19 December 2022, introduced the Democratic Republic of Congo in the list of high-risk third countries. This means that the

country is not able to ensure financial stability and this could infect the activities which are part of the global supply chain (Kumar et al., 2021). In recent years, some companies are trying to reduce the amount of cobalt used in LIBs because of the country social and political issues, which affect the cobalt supply chain and the price of this element (Deberdt, 2023; Scott & Ireland, 2020; Rajaeifar et al., 2022). For this reason some researchers are trying to find different options in order to substitute cobalt with other metals (Matthews, 2020).

The mining extraction sector of the DRC has always been characterised by artisanal work, indeed more than ⅕ of cobalt total extractions comes from artisanal mining, usually operated by local communities which do not use machineries (Calvão et al., 2021; Deberdt, 2023). This is a legal procedure, but frequently it is conducted without following the Mining Code requirements. Really often, workers do not have the right equipment to extract metals and the risk of contracting diseases is really high, moreover, they are exploited and not fairly paid. All this leads to corruption and environmental problems (Deberdt, 2021).

This complicated landscape affects the reputation of foreign companies which operate in the country, especially when it comes to child labour exploitation. In 2016 for the first time this social issue has been put under the spotlight and as a consequence some corporations started to take actions towards more responsible work (Deberdt, 2021). Programs to check the entire supply chain of cobalt have been established but the turning point has been the creation of the Entreprise Général du Cobalt S.A (EGC), owned by Gécamines with just 5% government owned, with the aim of avoiding child labour and bad working conditions in the DRC cobalt mining. This changed completely the DRC cobalt industry (Deberdt, 2021; Muroki, 2022).

Some companies started a collaboration with cooperatives and non-governmental organisations which actively try to improve life and working conditions, regulating the cobalt mining sector, in order to ensure workers rights and provide them with decent wages and reasonable labour conditions. This also helps foreign corporations to have a better visibility globally (Calvão et al., 2021).

Beside the EGC, the OECD Guidelines of 2011, the World Bank efforts to promote commitment with artisanal mining and the US Dodd-Frank Act of 2010, helped the improvement of the cobalt mining industry (Calvão et al., 2021).

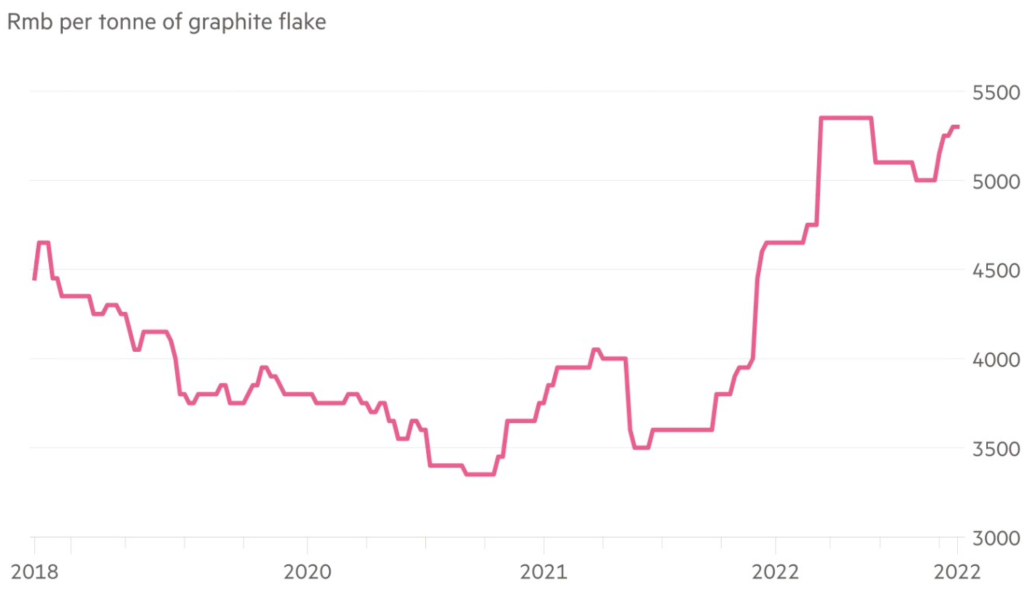
Once extracted, cobalt has to be refined to create LIBs cathodes. At the beginning of 2019, the DRC government tried to internalise this process by interdicting companies to export the extracted cobalt and performing the process inside the country. The answer from firms was not long in coming. The government was forced to delay the prohibition since companies raised their concern regarding the lack of reliable supply of electricity, necessary to refine cobalt. In this scenario, some Chinese firms started to invest in the country and build refineries, increasing DRC exportations of refined material over the years. This is the reason why nowadays the refining process is handled by China, where major players are Zhejiang Huayou Cobalt Co. Ltd., Jiangsu Cobalt Nickel MetalCo. Ldt. and GEM Cobalt Industry Co.. Just 20% of the global production is managed by Freeport Cobalt in Finland. Minor producers are Glencore, Umicore, Chambishi (Matthews, 2020).

2.2.1.3 Graphite

Graphite, which is non-metal (Scott & Ireland, 2020), is used to generate the anode of the EV battery (Coffin & Horowitz, 2018). Being graphite the third element for quantity to be used in LIBs it is quite important. Actually, nowadays, the battery sector is not the major consumer of graphite but it is expected to grow fast in the next few years, due to EVs sales increase. There are three types of graphite: *natural graphite*, which is obtained thanks to deposit extraction, *artificial graphite*, resulting by coke or coal processing and *blended graphite*, produced combining the previous two. Artificial graphite has better performances compared to the natural one but it is more expensive (La Monica et al., 2020; Tsuji, 2022). It is mainly produced and exported by China, US and Japan (Scott & Ireland, 2020).

The biggest reserve of natural graphite worldwide is hosted by Turkey (Scott & Ireland, 2020; Tsuji, 2022), which accounts for around 90 metric tons in 2022. Despite this, China is the major miner and supplier in the world, extracting 65% and refining 85% of the total amount of graphite in the world (Dempsey, 2022). It is followed by Mozambique, Madagascar and Brazil (Garside, 2023a; Tsuji, 2022). Indeed, with approximately 850,000 metric tons over 1.3 million metric tons produced in the entire world in 2022, China is leading this market (Garside, 2023a). Mines in the country are now concentrated in Heilongjiang province and Inner Mongolia region, after reserves in Shangdong province started to run out (Tsuji, 2022). It has been estimated that, due to the increase of EV sales, the demand for natural graphite could triple (Dempsey, 2022). China's leading position is possible thanks to its low costs of production which make it difficult for other countries to enter this market (La Monica et al., 2020). Furthermore, in just one year the price of this element has swollen significantly due to the increasing interest in EVs. In the graph below, it is possible to notice that in just almost two years, the price increased by Rmb1,800 per tonne ($250), reaching Rmb5,300 ($740) at the end of 2022 (Dempsey, 2022).

Figure 8: Graphite prices have risen as EV demand takes off



Source: Dempsey, “Tesla supplier warns of graphite supply risk in ‘opaque’ market”, 2022.

In 4 years, until 2021, ⅓ of the total imports of USA natural graphite were imported from China (Garside, 2023a).

The most important supplier of graphite for LIBs is Shenzhen BTR New Energy Materials Inc., which sells its product to LIBs producers like Samsung SDI, LG Chem and Panasonic (La Monica et al., 2020). Other important suppliers are Jiangxi Zichen Technology Co. Ltd., Ningbo Shanshan Co. Ltd., Guangdong Kaijin New Energy Technology Co. Ltd., and Hitachi Chemical Co. Ltd.. Except for the last one, which is a Japanese company, all the others are from China. In recent years USA and Europe also entered the global competition and, thanks to the new green standard imposed by both areas, they are expected to grow fast (Tsuji, 2022).

As for cobalt, the graphite refining process is led by China, followed by Japan and Korea (Scott & Ireland, 2020).

2.2.1.4 The Critical Raw Materials Act

In recent years, thanks to the evolution the EU is experiencing in terms of industrialization, urbanisation and technological advancement, the global demand for rare earth and batteries raw materials sored. This situation, together with the global events like the Covid pandemic in 2019 and the Ukrainian war in 2022, has raised concern towards issues which had never been taken into consideration before in this sector. Raw materials are mainly imported in Europe from foreign suppliers, which are exposed to high supply risk. Problems like supply chain disruption, price instability and monopolistic practices of few dominant suppliers become the starting point for the development of an european strategy, based on ensuring sustainable supply of these materials and trying to reduce dependence from external subjects (*Critical Raw Materials: ensuring secure and sustainable supply chains for EU's green and digital future*, 2023, p.1; Proposal for the Batteries Regulation, 2023)

The first action at European Union level, towards a more regulated environment, was taken in 2008, with the Raw Material Initiative (RMI). Its aim was to ensure access and sustainable supply of raw materials, in an European framework characterised by fair access to third countries resources for all the companies. Sustainability and recycling were considered key issues for the success of this initiative (*Raw Material Initiatives | IMA Europe*, s.d).

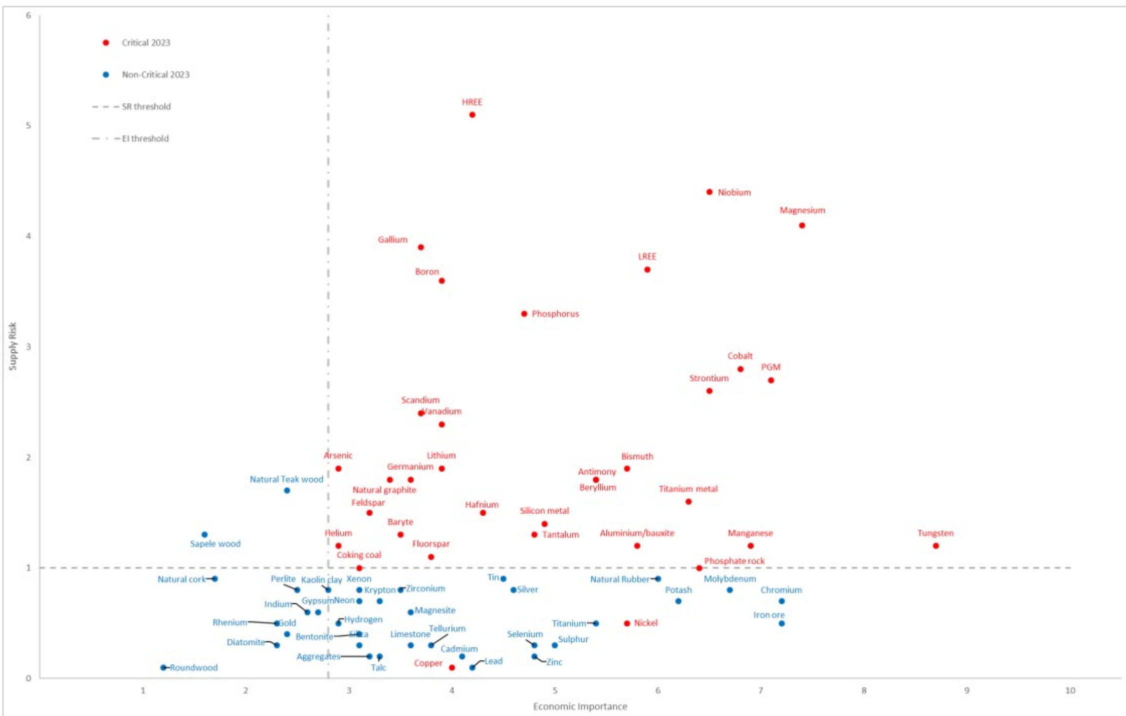
In 2020, with the action plan on critical raw materials (CRM), centralised on promoting stronger international relationships with third countries in order to ensure diversification of CRM suppliers and reinforcing the domestic supply chain, the regulatory process towards a more secure and fair market took a step forward (Critical Raw Material Act, 2023).

The most important piece of legislation, at European Union level, in this scope, is the Critical Raw Materials Act (CRMA). It was approved on the 16th March 2023, together with the Net Zero Industry Act, by the European Commission. Both of these documents are considered as a support for the achievement of the accomplishment of the EU Green Deal goals (*EUROBAT statement on the European Commission's Net Zero Industry Act and Critical Raw Materials Act*, 2023).

The CRMA is a legislative framework whose primary objective is to promote responsible and sustainable actions throughout the raw material value chain, fostering recycling practices. It aims at avoiding supply disruption by varying the suppliers through which the CRM are imported. This piece of legislation should also allow companies to obtain foundings and shortening procedures to generate projects related to CRM. Moreover, all this regulatory framework aims to address issues related to social and environmental impacts associated with the CRM processes, creating trust in people towards a topic which is perceived as a menace for the society and the environment (Critical Raw Materials Act, 2023).

In order to define a CRM as such, the European Union stated two parameters. The first one is the *economic importance* the material has for the economy of the EU in relation to how it is used in the final product and the actual value added at the product itself. The second one is the *risk* that there could exist if the *suppliers*, of these elements, would decide to stop its action in providing the EU with the materials itselves (*Critical raw materials*, s.d.; Grohol et al., 2023, pp. 1; Critical Raw Materials Act, 2023). Sustainability and environmental impact of an element are important factors too. Stating these two criteria, it has been possible to construct the graph represented by figure 9, where all the elements represented by red dots are considered as critical (Grohol et al., 2023, pp. 5).

Figure 9: Results of the 2023 EU criticality assessment



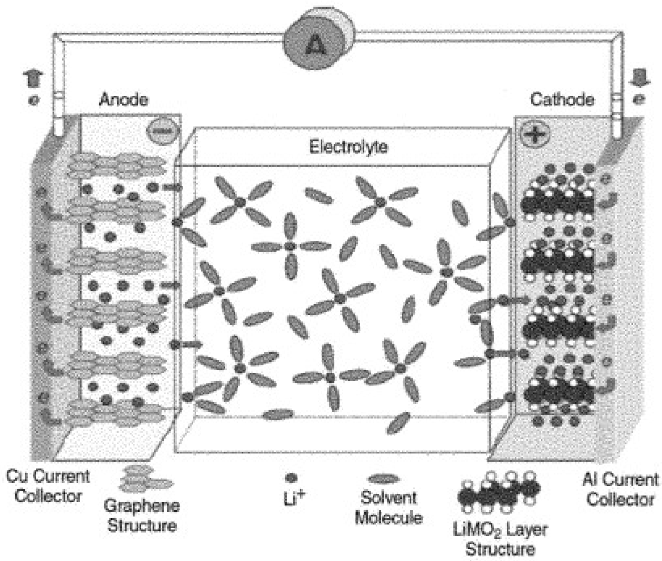
Source: Grohol et al., "European Commission, Study on the Critical Raw Materials for the EU 2023 – Final Report", 2023.

Thanks to these parameters, the European Union defined a list of critical raw materials, which serves as the basis for strategic planning and policy formulation. It is possible to find this list in session 1 of Annex II of the regulation. It is updated every three years and the first list was published in 2011. At that time it counted just fourteen elements. Along the years, some materials were removed and some others added. Nowadays it has reached thirtyfour materials among which we can find lithium, cobalt and natural graphite (Grohol et al., 2023; Critical Raw Materials Act, 2023; Proposal for the Batteries Regulation, 2020). Great importance is given to these elements because they are fundamental components of LIBs.
Another important aspect of the CRMA, which is worthy to be mentioned, is the difference between critical raw materials and strategic raw materials. These latter have a significant strategic importance in terms of technological advancement and in the achievement of green goals, they are responsible for possible inequalities in global supply and demand (*Critical Raw Materials: ensuring secure and sustainable supply chains for EU's green and digital future*, 2023, p.1).

2.2.2 Lithium-ion battery production

Following our path along the global value chain of the LIBs, after raw materials are extracted and refined, they are used to create the smallest part of a battery, the **cell**. Multiple cells put together create a **module** that, assembled together with other modules, creates the final **battery** which will be then integrated into the **EVs**. *Cell manufacturing*, *module manufacturing* and *pack assembly* are the three phases the battery manufacturing supply chain is composed of (Coffin & Horowitz, 2018).
The basic element of the lithium-ion batteries is the electrochemical cell which is composed of three elements: the *cathode* made of cobalt, the *anode*, whose main component is graphite, and the *electrolyte*, where organic carbonate solvents, containing dissolved lithium salts, comprise it. This last one has the task to connect electrically the first two components, which are physically separated by a plastic film full of pores. When the lithium ions move from the anode to the cathode passing by the electrolyte the battery enters operation (Coffin & Horowitz, 2018; Halimah et al., 2019).

Figure 10: The structure of a lithium-ion battery cell



Source: Coffin & Horowitz, "The supply chain for electric vehicle batteries", 2018.

A considerable amount of electrochemical cells, assembled together, creates a battery module. In turn, different battery modules connected electrically, together with refreshing, charging and power management systems, generate an EVB pack, applicable on the EVs (Jussani et al., 2017; Coffin & Horowitz, 2018).

When examining LIBs value chain, production of cells represents 70% of the total LIBs value chain value added, whereas the assembly stage and electrical and mechanical components together account for 25% only (Scott & Ireland, 2020). The scenario is similar if considering the costs supported by companies for the realisation of a battery pack. On the overall costs, the cell stage represents 75%, 25% if considering the general manufacturing process costs (Scott & Ireland, 2020), the module creation just 11% and the battery pack 14% (Coffin & Horowitz, 2018).

Starting from 2010, when prices of batteries packs accounted for $1,160 kWh, they have slightly decreased until 2022 when, consequently to the rise of raw materials costs, for the first time, lithium-ion batteries pack prices reported an increase of 7% compared to the previous year, reaching $151 kWh. Even though prices went up, it has been predicted that they will decline again until $100 kWh by 2026 (Dempsey, 2022a).

As for the extraction and processing of raw materials, Asia has a strong presence in the supply of components and creation of batteries. Chinese, Japanese and South Korean companies hold a dominant position in this phase especially for the production of cathodes and anodes

(Carrara et a., 2023; Coffin & Horowitz, 2018; Scott & Ireland, 2020). This is also evident when it comes to prices of lithium-ion packs. If comparing China, which is the most developed market with Europe and USA, batteries are cheaper since costs of production are lower (Dempsey, 2022a).

2.2.2.1 Gigafactory phenomenon

The word "gigafactory" or "megafactory" is nowadays commonly used to refer to those industrial plants where LIBs are produced. Actually, this term was first used by Elon Musk, CEO of Tesla, to speak of Tesla's manufacturing plants. The term refers to the unit of measurement, GWh used to evaluate the energy storage capacity of a plant (Gifford, 2019; Gennari, 2023).

A gigafactory is a factory where lithium-ion cells and modules are produced. There are some plants in which modules are also assembled into battery packs and directly integrated into the EVs. These procedures, carried out in a single place, enable the production of the final product to be faster, cheaper and more sustainable, since transportations of intermediate materials, which cause carbon emissions, are cut to zero. When all the different phases can not be realised in a single spot, it is suggested to locate them one close to each other. In this way, it is safer to move products from one place to another, since battery components are defined as high risk products, moreover, emissions are reduced to minimum (Gifford, 2019).

The creation of a gigafactory requires time, especially to obtain the permission to start the construction. Once the building is finished and the production starts, at the beginning the company does not produce its maximum capacity. To achieve such a result the plant needs time (Gifford, 2019).

The first in giving birth to this new phenomenon, after Tesla, were South Korean companies like LG Chem and Samsung SDI, which set their plants in China and Europe starting from 2015. From that moment on, the number of megafactories built all over the years increased rapidly (Moores, 2021).

The number of electric vehicles sold in Europe is expected to grow in the next few years. As a consequence the demand for electric batteries will grow. To cope with these changes, at the end of the first trimester of 2020 the request of new gigafactories in Europe started to increase rapidly (Gifford, 2019; Moores, 2021; Gennari, 2023).

This stage of production is led by China which hosts the majority of the megafactories present in the world (Moores, 2021). In 2022, just the city of Pechino produced almost 80% of the worldwide production which is expected to account for almost 2,451 GWh this year (2023). It has been calculated that at the end of 2023, 236 gigafactories, in all the world, would be producing at their expected capacity and more than 150 additionally are expected to be operational by 2030 (Gennari, 2023).
Production capacity of Europe now is not enough to supply all the continent's demand. This is the reason why a great amount of products are imported mainly from China. Building gigafactories in Europe, would be a value added for its member states. In this way, the dependency from China could be reduced, moreover it would be possible to avoid costs of transportation and import taxes which have to be supported when buying batteries from East Asia (Gifford, 2019).
The European production capacity is expected to increase in the next few years, also thanks to the legislations which are going to be implemented to substitute the fossil fuel with the electric (Gennari, 2023).
The installation of megafactories has direct effects not just on the economy of the area where the factory is built, but also on the social stratum which lives in that region. Indeed, it generates new job opportunities not just in the plant but also along the whole supply chain (Gifford, 2019). It has been estimated that a new infrastructure whose maximum production capacity is 40 GWh annually, can employ more than 3,000 people (Campagnol et al., 2022).
Another important aspect which should be taken into consideration is the price at which LIBs are sold. It fell more than half from 2014 to 2020, reaching $110/kWh, even though in the last years it registered a slow down (Moores, 2021). This was also related to the LIB pack price which decreased by almost 90%, from 2010 to 2020. In the last two years this decrease has reversed course, indeed because of the lack of raw materials and suppliers problems related, prices of the different components of LIBs started to slightly increase (Rajaeifar et al., 2022).

Gigafactories worth to be mentioned in Europe are Tesla’s in Berlin, Samsung in Hungary and Northvolt in Sweden, with respectively 100 GWh, 30 GWh and 32 GWh per year (Gifford, 2019).
Tesla, the first in creating a gigafactory in Nevada, last year (2022) inaugurated the first Tesla’s gigafactory in Europe and more precisely in Berlin. This plan, which is expected to

produce 500,000 vehicles annually, could help Tesla’s Shanghai gigafactory, which is overloaded with work after covid pandemic. Indeed, during the pandemic, Chinese production was slowed down. They produced goods for foreign clients delaying the home production. This gave the opportunity to other competitors to enter the market and satisfy the demand of goods which Tesla was not able to serve (Yu & Zhou, 2022). The implementation of the gigafactory in Germany was not easy, its construction has been delayed because of bureaucratic issues, moreover people were really sceptical because of the great environmental impact the company could have had in terms of water resources. Another important issue, which should not be left behind is the lack of materials needed to produce LIBs like semiconductors or electrical components. In fact, some Tesla’s competitors which are operating in Europe, after the Ukrainian war, were forced to prolong their production because of the lack of materials that they needed and usually provided by Ukrainian companies (Miller, 2022).

It has been noticed that the production stage requires a great amount of energy. Unless this energy is produced through renewable sources, like geothermal, wind or solar energy production, it generates emissions of greenhouse gases which have a great impact on the final outcomes and can create environmental pollution. Differently from fossil fuelled cars, electric vehicles generate more emissions in the production stage than during its usage. It is also important to mention that the energy used to manufacture LIBs should not affect the resources generated to provide everyday consumption (Rajaeifar et al., 2022).

2.2.3 End of life of lithium-ion batteries

2.2.3.1 Disposal, second use, recycling

Means of transport are one of the major producers of greenhouse gases globally, this is the reason why the EU as well as other countries like USA, has started a decarbonisation policy of this sector, trying to reduce the air pollution and mitigate the climate change, achieving temperature specific standards imposed.

The transition towards the electric is the first step to reach these goals. It has been predicted that, in the next twenty years, in the EU, the numbers of EVs sold will grow fast, reaching 7 million early by 2025 (Sommerville et al., 2021). As a consequence, the global supply

capacity of GWh, which soared in 2019, is expected to increase even more rapidly until 2030. This will produce two results: an increasing demand of the raw materials in order to manufacture new LIBs and the generation of battery waste which will have to be managed in a responsible way (Rajaeifar et al., 2022; Sommerville et al., 2021). Let us imagine that just more than one million cars whose battery weighs 250 kg can produce an amount of wasted battery material equal to 250.000 tonnes (Harper et al., 2019). It has been estimated that in 2030, the increasing sales will generate an amount of discarded LIBs of around 1.6 million tonnes, half of which coming from EVs (Rajaeifar et al., 2022).
In order to cope with these issues and give a better overview of the problem, different options will be presented.
Once the LIB comes to its end of life, it has to be removed from the electric vehicle. This action, as well as the following, is really delicate. It should be done by a capable workforce, using the right techniques. After this, there are three possible options which could be implemented: the *disposal*, the *reuse* or the *recycling* of the battery (Rajaeifar et al., 2022).
In the first case, the *battery disposal*, the power units are not used anymore, they are gathered and sent to landfills where they are converted into garbage. In this way the risk of generating environmental pollution and health issues is really high, if not treated in a responsible way. Indeed, when safety conditions are not respected in landfills and batteries are left for a long time without any control or inspection, fire hazards are more likely to happen. Due to the materials the lithium-ion battery is made of, internal temperature can increase and lead to combustion, causing fires which release harmful gases for the health and the environment. This can also happen because, during the removal stage, the condition of the battery is not known, so a non-visible damage could cause incidents (Mrozik et al., 2021; Sommerville et al., 2020).
The second pathway is *battery reuse.* Usually it is preferred before recycling since the value chain of the lithium-ion batteries is extended and its disposal is postponed. In this circumstance, the battery still has the characteristics to be employed, but not longer in an electric car, since for instance its power is not at the highest levels anymore. For this reason, after its extraction the battery is analysed and eventual damaged cells are fixed. Once controlled, they are implemented into different solutions like for example energy storage or assembled into smaller size vehicles (Melin, 2018; Rajaeifar et al., 2022). Batteries which are usually reemployed, lack 20% of their overall capacity but they can be exploited for at least

another ten years (Mrozik et al., 2021). This action creates advantages from an environmental point of view, since it avoids the realisation of new batteries, which could be more damaging for the environment, saving more or less ¼ of the total greenhouse gases produced by the transport sector (Martinez-Laserna et al., 2018).

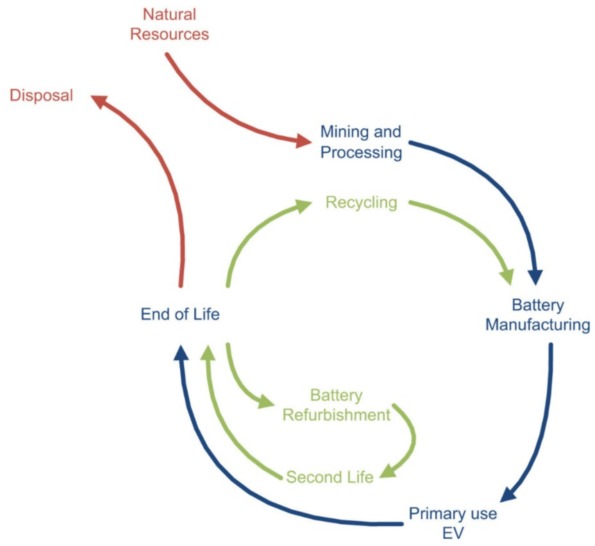
When considering the economic aspect, the second usage of the power unit has a consistent impact. LIBs which are installed in the EVs have high costs and this is reflected on the EVs prices. As a consequence, if considering a comparative car model, electric vehicles are not sold as easily as carbon fossil fuelled ones. Hence, the vehicle prices are one of the major obstacles to make this good affordable by everyone. In order to make it possible, the second usage could generate a discount in terms of costs for those people who would like to buy an EV (Martinez-Laserna et. al, 2018). Even though the reuse produces benefits, there are some aspects which have to be taken into consideration. For instance, until now there were no criteria to measure the health conditions of the power units, thanks to the Batteries Regulation approval, this aspect has been regulated and it will be implemented in the next few years. Another issue is the price at which goods with second life batteries are sold. For instance, if the price of a good with a reuse battery is the same as the one with a new battery, the consumer will prefer to buy the first one, limiting the distribution of goods with the already reemployed power units (Rajaeifar et al., 2022).

The third and last opportunity is *recycling*. This practice is still not well developed, indeed until a few years ago, just less than 5% of the total amount of LIBs sent to landfills were recycled in the EU (Sommerville et al., 2020). Thanks to recycling, it is possible to save almost 225 tons of minerals extracted from mines to produce one ton of refined lithium. Indeed, in order to produce that amount of ton of lithium, just 28 tons of worn LIBs are necessary, which becomes 250 when it deals with extracted minerals (Harper et al., 2019).

On the overall number of LIB components, thanks to the improvement of the technologies employed in the recycling stage, almost 40% of the constituents can be recuperated. Even though this percentage can have a consistent impact on the final outcomes, the recycling rate of LIBs is still pretty low (Mrozik et al., 2021). This is probably due to the fact that the implementation of LIBs EVs on the market is quite recent and not so many power units have reached their end of life yet. Furthermore, the second use of the power unit is preferred compared to recycling, this procedure creates a delay in the recovery of materials (Melin, 2018). LIBs can last up to 20 years but of course the recycling procedure alone can not serve

the entire future market. Mines and brines will be always working, even though less, to provide with additional material (Harper et al., 2019).
Henche, with the increasing number of EV sold globally, if recycling is now considered as an option, in the next few years it will become essential for the EVs market.
Thanks to this practice, as mentioned by Sommerville et al. (2021), some benefits can be achieved "*such as; decreased pollution, avoidance of toxic byproducts, reduced land demand in the case of landfills, lessening demand on finite resources and decreasing the environmental costs associated with mining virgin resources*".
This solution is thought as the last step after the second usage of LIBs, to reduce even more the environmental impact. As already mentioned in the previous paragraphs, nowadays there is a lack of raw materials needed to manufacture batteries, furthermore, the instability of the global supply chain does not give the opportunity to rely on it, whereas, on the other side, the global market of raw materials is expanding under the increasing global demand of EVs. For this reason, the LIBs recycling would give the opportunity to rely on a more stable and sustainable source of raw materials. Furthermore, recycling is the means through which the global value chain of LIBs closes its circle becoming a real *circular economy*, as shown in figure 11. In this way the life of a LIB does not stop with the disposal stage, drawing itself as linear, but it gives birth to a continuous cycle which reintegrates important elements of the power unit on the market (Sommerville et al., 2021).

Figure 11: Circular economy of lithium-ion batteries



Source: Martinez-Laserna et al., "Battery second life: Hype, hope or reality? A critical review of the state of the art.", 2018.melin

All the steps from the extraction to the discharge require a high level of employee specialisation since it is a health risky process. Nowadays the workforce necessary to do this activity is not sufficiently specialised. Furthermore, it is not even possible to use an automatic procedure to disassemble batteries in order to cut time, costs and to make it risk free for humans, since the manufacture of the power unit is not a standardised process (Harper et al., 2019; Rajaeifar et al., 2022; Sommerville et al., 2020). For this reason, recycling costs are quite high (Melin, 2018).

Another important aspect, which has to be taken into consideration, is the presence of *infrastructures* ready to host the recycling process. Nowadays, not all the European countries have specific locations where to conduct a recycling procedure. For this reason, some of them have to send the removed batteries from the EVs, to other countries which have the possibility to recycle them. Great Britain is an example. When it was still part of the European Union, it was used to rely on Belgium for processing used batteries, but due to the tight policy to access the market and to recycling, the UK had to delay its procedures which should not have happened if it had the proper infrastructures (Mrozik et al., 2021).

There are three main processes through which it is possible to obtain the recycled materials: pyrometallurgy, hydrometallurgy and direct recycling. This paragraph is not going to analyse in depth every single process but is going to focus on their *environmental impact* (Mrozik et al., 2021). If considering raw materials, thanks to the recycling, the impact of the life cycle of a LIB is halved, however it is not a completely zero emission process (Wang et al., 2014). Indeed, the pyrometallurgical procedure uses high temperature to obtain the materials. In doing so, greenhouse gases are emitted. They account for maximum 3.5% of the total emission in the battery life cycle (Rajaeifar et al., 2022) and they are the major contributors of phenomena like global warming and the enlargement of the ozone hole (Mrozik et al., 2021; Rajaeifar et al., 2022).

Hydrometallurgical process, on the other hand, requires big quantities of water, hence, if in the previous case the issue was related to the emission of substances in the air, in this one the spotlight is on the waste and contamination of water. In terms of direct recycling there is no consistent data to verify a possible outcome in terms of pollution (Mrozik et al., 2021).

LIBs are recycled in different parts of the world, but the most relevant countries are China with more than 20 companies which operate in this sector, South Korea with around 6 businesses, Japan, USA, Canada and a few countries of the European Union. As already mentioned in the previous chapters, China and South Korea are the major operators in the different stages of LIBs, for this reason also in this phase they have a predominant position. Indeed due to the high quantity of raw materials they need to produce new batteries, it is more convenient for them to rely on the recycling process in order to secure a good amount of resources needed to manufacture new goods. The batteries processed in South Korea and China come from different parts of the world like Europe which prefer to export them and make them be processed abroad. Also for this reason, the recycling rate of the continent is still low (Melin, 2018).

To conclude, electric cars can be a good answer to the environmental issues the world is experiencing now and the second use and the recycling are fundamental procedures to put into practice in order to make this shift towards a green automotive sector even more sustainable.

2.2.4 The batteries regulation (EUROBAT, 2023; Batteries Regulation, 2023)

In the complex legislative landscape of electric batteries an important piece of legislation is the Regulation (EU) 2023/1542 of the European Parliament and of the Council, also known as the Batteries Regulation. It is defined as Environmental Legislation 2.0 since as mentioned in art. 2, "*The objectives of this Regulation are to contribute to the efficient functioning of the internal market, while preventing and reducing the adverse impacts of batteries on the environment, and to protect the environment and human health by preventing and reducing the adverse impacts of the generation and management of waste batteries*".

The Batteries Regulation was proposed to regulate the different stages of the batteries life cycle. It was approved by the European Parliament on 14 June 2023, after a long period of revision, started in 2020 with the proposal of the European Commission and lasted more than two years. It was published in the Official Journal of the European Union on 28 July 2023. This piece of legislation is very important for the achievement of the goals of the European Green Deal and it is a product specific legislation. Indeed, differently from other types of law, like the Ecodesign Regulation, which regulate the realisation of eco products in general, the Batteries Regulation is focused just on batteries. The text's most important chapters are the following macro topics: *sustainability and safety requirements* (chapter II), *labelling and information requirements* (Chapters III, IX), *due diligence* (Chapter VII) and *management of waste batteries* (Chapter VIII). In each macro area different aspects are taken into consideration and in particular, the first three topics have the objective of enhancing the internal battery's market efficiency while promoting fair competition, whereas the last one is related to the environmental impact of the batteries lifecycle (Council of the European Union, 2023).

In order to apply the requirements set by the regulation, according to different characteristics, batteries have been grouped into five different categories: the Portable batteries, the Starting Lighting Ignition batteries (SLI), the Light Means of Transport (LMT) batteries, the Electric Vehicle batteries and the Industrial batteries. For those batteries which do not belong to any of the mentioned categories, they will be categorised as Industrial batteries, whereas if a battery fits more than one definition, the most strict parameters will be applied.

The implementation stage of this piece of legislation is quite particular and complex. Indeed the full text adoption will not follow a predefined timing. Some chapters and articles will have a different deadline of application.

Twenty days after its publication, the Batteries Regulation entered into force. Six months after entering into force the regulation will be applied (18 February 2024). The parts which do not follow the ordinary adoption are the following: Chapter VI and art. 17 (except paragraph 2)

on the Conformity assessment procedure, as well as some design requirements of Chapter II will be applied on 18th August 2024, one year more will be required for Chapter VII and Chapter VIII, to conclude, for art. 11 and Chapter IX on Digital Battery Passport the application date will be 18 February 2027.
The Batteries Regulation aims at not clashing with the already existing pieces of legislation which regulate the electric vehicle environment like the Euro 7 and UNECE GTR 22 vehicle requirements, on the contrary it tries to complete the legislative aspects of the electric batteries by promoting a circular economy.
Worthy to be mentioned in the Batteries Regulation is the labelling and information criteria. In order to give access to all batteries' data production, starting from August 2026, a label, reporting all battery's general information, should be applied to the battery itself. As reported in the regulation, general information states for

> "*information identifying the manufacturer…the battery category…the place of manufacture (geographical location of a battery manufacturing plant)... the date of manufacture (month and year), the weight, the capacity, the chemistry, the hazardous substances present in the battery…, usable extinguishing agent, critical raw materials present in the battery in a concentration of more than 0,1 % weight by weight*".

Moreover, to keep track of all the information, a *Digital Battery Passport* should be implemented. It is a document which gathers all related battery data, like the battery model, its composition, technical information and so on and so forth. Another important tool related to the battery passport is the *QR code* which should be implemented and put on the battery, to give direct access to some battery's information.
This piece of law aims at ensuring the proper handling and disposal of the power unit with a strong accent on sustainability and resource conservation. The guidelines for the collection, transportation and recycling of batteries try to minimise the potential environmental contamination and health risk caused by improper disposal. Furthermore, it contributes in reducing the depletion of raw materials and greenhouse gases emission phenomenon, adopting recycle technologies to recuperate important ores from batteries which have reached their end of life.

In essence, this regulatory piece of law plays a crucial role in steering societies towards a more environmentally conscious approach to managing battery waste, aligning with broader global efforts towards a circular economy and reduced ecological footprint.
It states that

> "*in view of the strategic importance of batteries, to provide legal certainty to all operators involved and to avoid discrimination, barriers to trade and distortions on the market for batteries, it is necessary to set out rules on the sustainability, performance, safety, collection, recycling and second life of batteries as well as on information about batteries for end-users and economic operators. It is necessary to create a harmonised regulatory framework for dealing with the entire life cycle of batteries that are placed on the market in the Union*".

Thanks to it, all member states of the European Union will have to align their actions by applying the same rules and criteria for all the stages of the batteries life cycle, ensuring coordination and better results in terms of waste management.
When it comes to collection, the responsibles in charge for this procedure are the producers of EVBs. Together with competent authorities, they should give birth to what the regulation calls "*collection points*" and they should gather all types of batteries even though, different from the ones they sell on the market. This step, together with the recycling, is really important in order to improve the autonomy of the European Union in the supply sector of batteries and give the opportunity to use recycled materials to manufacture new goods. Furthermore, the collection procedure should be promoted in all the territory of each member state by providing infrastructures which enable the end-user to collect the batteries. In addition, the producers and the distributors are in charge of giving the right information to the final user in order to collect the battery in a correct way.
The power units collected should be separated from other types of waste materials and put in sites which comply with specific conditions. Surfaces, for instance, should not allow substances to pass through them, or the materials used to cover the storaged batteries should avoid any type of danger.

After the collection, power units are prepared to be treated. In some situations batteries can be reused after specific controls, as ruled by article 72, which deals with the shipment of waste batteries also outside the European Union.
Once a Member State has collected all the material which has to be recycled, the treatment can be conducted in another European member state, as well as outside the European Union. If this is the case, all the procedures have to follow regulations stated by the European Commission, which ensure the right management of all the steps of this battery life cycle stage.

2.3 Alternative solutions implemented

Together with LIBs, other possible solutions have been implemented to reduce emissions and try to solve the environmental problems the world is facing nowadays. Different types of batteries have been created, using alternative materials in order to reduce their environmental impact.
More than twenty years ago, the first *sodium-sulphur battery* was realised. As suggested by its name they are mainly composed of sodium and sulphur, this makes the battery less efficient and less lasting compared to LIBs. Thanks to its production procedure, emissions of CO2 will be cut but a certain amount of greenhouse gases will be released anyway. Due to the fact that lithium, which is a critical material, is not used in this type of batteries, they are cheaper compared to LIBs. *Lithium-iron phosphate batteries* are another example. As for the previous one, prices are quite lower compared to LIBs, moreover they last longer, even though they have a smaller storage capacity (Habib et al., 2022).
An additional option, which has been subject of important discussions, has been the use of hydrogen to fuel vehicles. Compared to LIBs, this solution has a lower amount of critical raw materials used (Loprencipe, 2022), moreover, its autonomy is higher, it can travel almost the same distance of a conventional car. In addition, the timing to refuel a car is really fast, indeed, it takes less than five minutes to complete the operation. In terms of emissions, they are cut to zero; the only emission registered during the usage is water vapour (Dash et al., 2022; Turoń, 2020).
The negative aspects which can be highlighted in this solution is the amount of energy used to generate hydrogen, indeed to obtain this element a great quantity of energy is required (Loprencipe, 2022). Furthermore, to refuel and maintain these vehicles, specific

infrastructures are needed since this element is quite sensitive to be treated. Moreover, like for the EVs in the past years, the prices of a hydrogen car are really high (Turoń, 2020).

2.4 Conclusion

How it has been analysed in the previous paragraphs, in these years the European EVBs market has evolved and adapted according to the new pieces of legislation published by the EU. Indeed the European institutions are trying to rule all the aspects of the EVBs in order to make a conscious use of this new technology. It is possible to affirm that the EU is leading this procedure in order to prevent possible future environmental disasters. LIBs seem to be an essential element for the transition towards a greener and sustainable Europe.

The literature, which has been examined to write the first chapter, presents a well detailed overview of each phase of the LIBs GVC, highlighting both negative and positive aspects of this integrated structure. In the entire text, it is strongly evident the Chinese predominance in all the stages of LIBs GVC. Indeed, its EV market is the most developed in the world. Furthermore, it has also been highlighted that the concept of GVC has changed over the years. Thanks to the implementation of new practices such as the reuse and the recycling, the concept of circular economy has been integrated in LIBs life cycle.

The next chapter will investigate those aspects which are responsible for sustainable development and the UE action in response.

CHAPTER 3
METHODOLOGY

After a general presentation of the GVC, where positive and negative aspects have been highlighted, the literature review had the aim of presenting and analysing the entire LIBs GVC, with a special focus on its environmental impact. International papers and studies on this topic, as well as European regulations have been relevant in the first phase. Being LIBs implementation in EVs an evolving topic, and a quite new theme, newspapers articles have been fundamental to keep track of the latest information not yet examined in the academic works.

The methodology chapter aims at motivating the research approach explaining and investigating those barriers and enablers to sustainable development in the GVC of EVBs and how the EU is addressing these challenges through its policies and initiatives from companies point of view.

3.1 Research approach

According to the research goal and the desire of the person who is conducting the research, there are two possible research approaches. The quantitative and the qualitative one. The first one is suggested for those researches which lack time and resources. Its aim is to quickly generate data through specific instruments like surveys, which are spread around a large number of people. Whereas, if the topic we are investigating is new and not well known, so we need to collect as much information as possible, a qualitative approach will be preferred. In this case, tools used to gather relevant details are interviews, focus groups, documents revision etc. Moreover, the qualitative approach analyses how different variables can influence a specific circumstance. According to the aim of the study one approach rather than the other will be used (Hancock et al., 2021).

Since the topic of this thesis is contemporary and it is not well known by the population, a qualitative approach has been chosen to conduct the research. Guidelines from Marshall and Rossmann (2014) have been followed.

There are different ways to manage qualitative research. In this specific project, the case study approach has been chosen.

As defined by Yin (1994), "*case studies are rich, empirical descriptions of particular instances of a phenomenon that are typically based on a variety of data sources*". The aim of a case study research is to deeply investigate current phenomenon within its authentic real-world setting, particularly when the distinction between the event and its context are not readily apparent (Baskarada, 2014).

Thanks to the case study research, it is possible to come to know in a deeper way the analysed phenomenon, through which the researcher can find explanations to answer the research question previously presented. In this specific research, the results obtained will be presented in a narrative way to support the goal of the study (Bagherzadeh, 2018).

According to Hancock et al. (2021), the case study research has specific characteristics. First of all, the subject of the analysis can be a person, an organisation or an event. Secondly, it has to be examined in its natural ambience. Lastly, due to the great amount of information which is gathered through this method, outcomes are presented in a narrative way in order to deeply describe the subject of the research.

The rich amount of data which can be gathered through the research approach are analysed and, thanks to a triangulation technique, they contribute in giving more confidence to the final conclusion (Patton & Appelbaum, 2003).

In order to obtain a useful case study analysis, as shown by Patton & Appelbaum (2003), different aspects need to be followed. First of all, it is really important to have a clear understanding of the object to be studied. Secondly, it is significant to choose an appropriate case study which is in line with the scope of the research and which could give a relevant contribution in the investigation. Thirdly, the presence of an initial theory, generated through a literature review, can help in choosing the case study and verify whether findings match with the literature analysed. In this sense, data gathering is an important procedure in order to build strong conclusions.

Even though the case study research can provide us with a clear understanding of a specific problem, some limitations can be highlighted. For instance, findings can not be generalised, indeed the contextual factors which make each case study unique, prevent the application of the results to other situations. Researcher's subjectivity is another aspect which could affect the final outcomes, hence the final report can be influenced by its perspective and background like past experiences and knowledge (Bagherzadeh, 2018; Patton & Appelbaum, 2003).

The following case study analysis will be a multiple case study design, with qualitative data gathering methods. Semi-structured interviews are the tool that have been used to conduct this qualitative research. This approach was chosen to gain insights from participants' experiences and enhance our understanding. Additionally, the investigation took into account existing documentation and reports that were readily accessible and available for reference.
Employing a case study approach, based on semi-structured interviews, enables participants to be more flexible and provide relevant information. Indeed even though the conversation is structured, it isn't confined by predefined margin and the participants are those who establish the parameters (Øidvin, 2023). Thanks to it, it is possible to deeply highlight the interviewees point of view.

3.2 Case studies selection

Case study selection is the first step of our analysis. As suggested by Stake (1995), it is possible to establish different measures to choose the right case study. The first one is the capacity of a specific case study to provide us with important information, which can help us in answering our research question. So, the example chosen should bring knowledge to the study. Sometimes, it is not easy to find cases and especially find out informants who can help us in collecting data. Another relevant aspect which has to be taken into consideration, when choosing among the different options, is the context of the selected cases. Before choosing one, it is important to be far-sighted and try to preview what possible outcomes could be, in order to understand whether the case we are considering can be relevant for our study.
In a qualitative analysis, when case study method is used, it is difficult to generalise the findings, whereas, the particularity of the case study analysed has to be highlighted. Once the case is selected the aim is to know as much as possible of it and to stress those elements which characterise its uniqueness. To sum up, it is fundamental to understand the case (Stake; 1995).

Thanks to a six months internship in Brussels, working for EUROBAT, Association of European Automotive and Industrial Battery Manufacturers, I had the possibility to enter in contact with different companies in the battery landscape, such as extractors and refiners of raw materials, manufacturers and sellers of EVBs. For this reason, I decided to try to gather

information from their representatives. It has been quite easy to contact some of them and they have been available to contribute to my analysis.
The research question aims at investigating companies' point of view for a sustainable development in the batteries sector, and trying to understand what the position of the EU in terms of policies and initiatives is. In order to select companies which could have been relevant for the result of the study, some characteristics have been taken into consideration. Firstly, since I wanted to examine the enablers and barriers of sustainable development, it has been important to focus on companies which present a commitment in environmental sustainability actions. The companies to whom questions were submitted are trying to improve their activity by reducing their environmental impact. Secondly, data availability on projects and initiatives of the companies' interviewees has been another relevant aspect.
Before choosing the participants some criteria have been stated. Three moments along the LIBs GCV have been identified: the extraction and processing, the batteries manufacture and the after use stage. Furthermore, the geographical position has been taken into consideration. The company's geographical position has been useful to understand the different points of view of those businesses which are conducted outside the EU and those which are part of the Union. Table 1 below shows the companies which took part in the interviews.

Table 1: Companies involved in the interviews

Company	**Activity Conducted**	**Headquarter**	**Geographical Position Subsidiary Interviewed**
Albemarle Europe SRL	Extraction and processing	USA	Belgium
FREYR Battery Norway	Production of batteries	USA	Norway
Exide Technologies	Production of batteries	USA	Germany
DENIOS	Shelters producers	Germany	Italy

3.3 Data collection

Case studies aim at achieving a better overview of a phenomenon, therefore analysing just one data source can be limiting. For this reason, I tried to base my analysis on different sources to gather relevant information. The analysis was based on two different types of data. Primary data sources which have been collected through semi-structured interviews, then triangulated with different secondary data sources. In this way, it has been possible to verify the presence of inconsistency in the data material. Thanks to a triangulation procedure, available information and details obtained through interviews have been put together in order to validate results and find an explanation for the research question (Patton & Appelbaum, 2003).

3.3.1 Semi-structured interviews (primary data)

As mentioned by Baskarada (2014), "*interviews are guided conversations that are usually one of the most important sources of case study evidence. However, they should only be used to obtain information that cannot be obtained in any other way*". In particular semi-structured interviews are generally used to understand the participants' points of view in a more flexible way, enabling the researcher to concentrate more on some interesting aspects and asking for clarification. It gives the possibility to refocus on answers which have not been exhaustive. Furthermore, it gives the opportunity to modulate questions according to the responses received.

Conducting an interview is not easy. As presented by Kasunic (2010) and Baskarada (2014), the researcher should be able not to miss the point and focus on the meeting object, managing the time in order to obtain all the answers needed.

Some limitations can be highlighted, for instance the direct interaction with the participant can generate misunderstandings, in addition, comments can have an influence on the response received. These aspects could be mitigated through the interviewer's attitude.

Recording devices can be used while conducting the interviews. They can be useful to transcribe the conversation and review it in order to have a better overview of the discussion. If some clarifications are needed, it is recommended to ask for it as soon as possible (Kasunic, 2010).

In this specific study, the semi-structured interview technique has been selected, given the reduced number of participants and their job position.
Questions were opened and they were structured according to the type of business conducted by the company and to the participants' field of interest. Indeed companies which took part in this project belong to different stages of the LIBs GVC. A common thread has been followed, a few general questions were provided to everyone, whereas some others were modulated according to the interviewee's sphere of activity.
Primary data have been collected in two different ways. All the participants were provided with a written document, where they could answer their questions. One of them sent its written answers via email, some others preferred to have a colloquial online conversation, lasting on average no more than 40 minutes. In this second case, it has been possible not just to follow exactly the default questions but also ask clarifications and follow-ups in real time. In this situation it has been important for the researcher to try to set up a positive relationship with the person interviewed. To obtain such an environment, after questions were provided, it was given the interviewees some days to become familiar with them and prepare themselves for the interview. During the online meeting, the conversation started by giving a general overview of the thesis subject and the research question I am trying to find an answer to. After this, I started collecting data, focusing on time management and asking for explanations when needed.
Due to the fact that participants live in different parts of the world, the only way to have a conversation with them was online meetings, which were made by relying on a digital video call software. Thanks to it, it has been possible to conduct interviews in a limited period of time. During the conversations, notes were taken and the interviews were recorded, just after the consensus of the person concerned. Thanks to it, once the meeting was finished, the records were transcripted and sent to the interviewees for eventual checks. The notes taken and the records have been useful to give birth to the first material then used to present the results.
In the non-in person interviews, it has been important the availability of participants for further explanations and follow-ups.
Being the transcription of the interviews a procedure which takes a lot of time, I thought to use a transcript software, but because of the spelling mistakes and the possibility of losing

important aspects like verbal tone which can suggest important information, I agreed that it would have been better to transcribe the interviews manually.

A total of 17 companies/people, operating in different stages of LIBs GVC have been contacted. Just 6 of them replied to the email sent. At the end, the total number of interviews obtained is 4, 1 written and 3 oral. They were taken in October 2023. An interviews' overview is presented in table 2.

Table 2: Interviews' information.

Company	Participant	Position	Format
FREYR Battery Norway	Hege Marie Norheim	EVP, Corporate Public Affairs and Sustainability	Oral interview
Exide Technologies	Karsten Kurz	Director CSR & Governmental relations	Written
Albemarle Europe SRL	Francesco Gattiglio	Director External Affairs, EU	Oral interview
DENIOS	Pietro Repetto	Sales Manager	Oral interview

3.3.2 Secondary data

The interviews were cross-verified by a range of documents in order to achieve a rigorous comprehension of the case study.

Documents which helped in the triangulation process have been newspaper articles, press releases, summaries of conferences as well as reports generated by the private corporations, research institutions, analytical firms and governmental entities. Other important documents which played a key role have been available documents of the company such as articles, press releases, annual reports, technical documents and environmental, social and governance reports. During the initial phase, these documents provided me with an extensive overview of the company business and its involvement in sustainability actions, as well as their relation

with the context of the research project, giving a more complete insight to the data produced with the interviews.
Companies' documents have been treated with care, since they might hide the critical aspects which could be found in some other papers.

3.4 Methodological limitations

In conducting the research, some limitations have been highlighted. The number of people who participated in the interview is quite small. This was limited by the little period of time available. If from one side, the sample size can be considered not sufficient, from the other side, being this study a qualitative research, the aim is to place greater importance on examining the significance within particular situations, as opposed to actively seeking representation.
Another important aspect, which should be taken into consideration is the answers received. Being the interviewees representatives of their companies, they could have hidden some negative aspects, by showing just the positive side. Furthermore, even though the companies interviewed are focused on the sustainability aspect, this element is a critical one, for this reason informants could have provided divergent details on sustainable behaviour.
In conclusion, as argued by Bagherzadeh (2018) and Patton & Appelbaum (2003), findings of one case study can not be generalised as representatives of a phenomenon. As a consequence the transferability aspect can not be taken into consideration.

CHAPTER 4
FINDINGS

This chapter will present the findings of the qualitative research conducted. Thanks to primary and secondary data, results have been elaborated and presented. Interviews and revision of additional documents have been important to write this paragraph. After a brief explanation of each company's field of work, their point of view in relation to the research questions will be presented.

Since this thesis tries to analyse those elements which could allow a sustainable development and those which would stop it, from companies point of view, businesses operating in different stages of the EVBs GVC have been interviewed.

The chapter is divided into sessions, corresponding to the companies selected. The first session analyses Albemarle Europe SRL, extractor and refiner of lithium, the second one FREYR Battery Norway, a soon to be cell producer, the third one Exide Technologies, a seller of batteries and the last one DENIOS, a shelter producer.

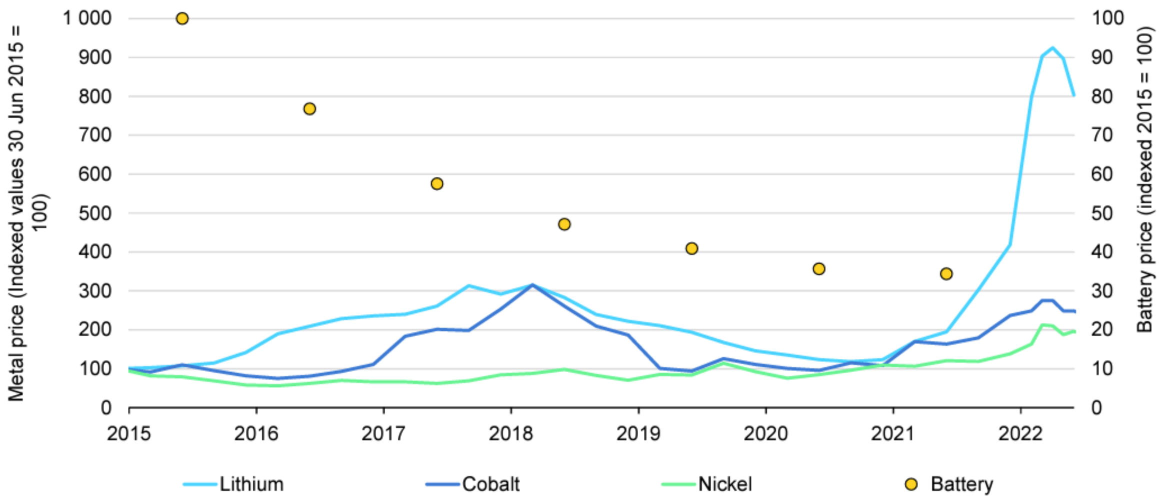
The common thread of the findings is sustainable development, from an industrial and legislative perspective.

4.1 Albemarle Europe SRL

Albemarle Europe SRL is part of Albemarle Corporation, which has its headquarter in the USA and it is one of the biggest companies in the world which extracts and refines lithium, the main component of LIBs. With a market cap of US$ 25.65 billion in 2023, it operates mostly in Chile, in particular in the Salar de Atacama (Barrera & Kelly, 2023; LaRocca, 2020; La Monica et al., 2020) and in small part also in the USA and in Australia through joint ventures. Their main refinery is situated in China. They conduct both types of lithium extraction procedures, from brines and from mines (Albemarle Corporation, 2022).

In 2022, lithium price hit a peak never seen before. Due to the increasing demand for batteries, the supply chain concern and the availability of materials after the effects of the pandemic, prices of raw materials soared. Cobalt and nickel doubled their prices and lithium price increased seven times more than the previous years (International Energy Agency, 2022). Figure 12 gives a good explanation of the phenomenon.

Figure 12: Battery metals prices, 2015 – July 2022



Source: International Energy Agency, "*Global Supply Chains of EV Batteries*", 2022.

This high request of lithium, put attention on the sustainability aspect.

Albemarle has an important responsibility in terms of sustainable actions along the LIBs global value chain. On their website (*Sustainability | Albemarle*, s.d.), it is possible to see their commitment in this area. They stated some sustainability targets such as the abolition of carbon emissions by 2050, or the reduction of the amount of freshwater used by 2030.

Some actions, that see the usage of renewable energy, to reduce carbon dioxide emissions, have been already put into practice. For instance the usage of photovoltaic facilities, in one of their centres, or the conclusion of renewable energy contracts. Their lithium GHG intensity has reduced over the years. In 2019, it accounted for 2.9 mtCO2e/mt, reaching 2.7 mtCO2e/mt in 2022. This value is expected to never overcome 3 in the future (Albemarle Corporation, 2023). As suggested by Francesco Gattiglio, Director External Affairs, EU, the achievement of the sustainable targets is not easy, indeed

> "*There is a more important problem which is Trade Offs. We are already trying to make production as sustainable as possible, the problem is that it is difficult to do it for all things at the same time, so from one side we may be able to reduce the carbon footprint of extraction, but from the other we need to increase the use of water….*

I can give you an example, one of the criticisms that is often directed at lithium is that it is done by evaporating the water present in the brine. Therefore we are trying to do a new process called direct lithium extraction. Lithium is directly extracted from the brine which is reinserted under the desert. It would be an interesting system, the problem is that this system requires the use of freshwater, much more freshwater than the other system based on evaporation, so this is something we are trying to do, but we only do it if we can do it with desalinated water."

Being water a scarce resource, as presented in Albemarle Corporation (2022), they are concentrating their resources in the establishment of new technologies in order to reduce their water footprint, especially in those areas where risk is higher. By 2030, it is expected to reduce fresh water usage by 25%.

In order to enable sustainable development, Albemarle also puts a lot of attention in the approach with the communities which live in the areas where they operate, taking into consideration their opinion and point of view before making decisions. Great value is given to Albemarle participation in IRMA, Initiative for Responsible Mining Assurance, that, as explained by Francesco Gattiglio, helps companies which are part of this initiative to improve their performances and processes through fixed pass marks. It is a sort of guidance for the company, which helps them in establishing a future development trajectory.

Another important challenge for the company is the legislative inconsistency. Following all the standards which are required in the different countries is not easy. Even though they mainly extract lithium in Chile, their processes are influenced by other countries' regulations, since they export their product all over the world. As a consequence, European legislation has a strong impact on the Albemarle extraction procedure.

An important aspect which has been highlighted during the interview is the lack of attention from the EU, at the first stages of the LIBs GVC, extraction and processing. This issue escalated with the establishment of the IRA in the USA, which has started attracting investments and companies thanks to its financial support. Even though, from a geological point of view, the EU countries are poor of raw materials, the processing and realisation of elements used to create the cathode, are activities which can be put into practice. In this way, it would be possible to stop the dependency from other countries. In order to establish these

types of activities in the EU, an important element which should be revised is the cost of their implementation, since nowadays, the majority of these activities are carried out in China where costs are really low compared to those of the EU and USA. Financial issues are not the only problem in establishing these activities in western countries. The level of knowhow that China has is more developed compared to Europe or USA. Indeed, China has an experience of almost ten years of history which can not be compared with the immaturity of the European market. This is the reason why investments go firstly to China, then to the USA, because of the IRA, and lastly to Europe.
According to what explained in chapter 2, the recycling stage will have an influence on the raw material market, since parts of the element used to create the batteries could come from recycling and not from extraction. During the interview it has been discussed that, even though the recovery of raw materials from the recycling stage could contribute a lot in the market, reaching almost half of the material provided in the future years, it would never substitute completely the extraction procedure,

> "*...simply because there are still efficiency losses in recycling... and because lithium demand grows and will continue to do so, I don't think we can ever achieve a complete replacement. ...I think that from mid-2030-2035 we will start to have significant percentages, 2040 even more so. Before that it will be very difficult, because batteries simply have a fairly long useful life so they will not yet enter the recycling process.*"

The interest in recycling batteries in Europe or in the USA is really strong, since sending them to China, to conduct the procedure, has an environmental cost, and creates strong dependency from the country. Indeed, recycling will become an important stage in the next few years, which should be promoted and developed, in order to ensure security of supply. Also the second life of a battery is really important but in this case there are different aspects which should be analysed to understand whether it is convenient to implement the already used batteries in a second use, or it is better to directly recycle it. As suggested,

> "*... a battery can last 10/15 years...so when it is removed from an electric car, after 15 years of use, it has to compete on the market with new batteries that have*

been developed with 15 years of technological advantage, so it is important to see what its actual efficiency of the battery is and whether it makes sense to recover the materials…"

As it will be mentioned in the FREYR case study, among all the European steps towards sustainable development, the EU could improve its action in the carbon footprint requirements. As declared during the interview, there are some laws like the Carbon Border Adjustment Mechanism and the threshold to be respected for the carbon footprint but till now there is a little bit of inconsistency in all these policies.

4.2 FREYR Battery Norway

FREYR Battery Norway is a Norwegian company, part of FREYR Battery Group, which is setting its basics to produce eco-friendly battery cells for electric vehicles, energy storage and marine means of transport. As mentioned in their annual report (FREYR, 2022) their mission is "*to accelerate the decarbonization of energy and transportation systems globally*". Indeed, their ambition is to produce batteries by reducing the actual amount of CO2 emitted by the global average. As came to light in the interview with Hege Marie Norheim, Executive Vice President, Corporate Public Affairs and Sustainability, FREYR Battery Norway is still not producing batteries, they are working on the final decision to start their activity. They will produce LFP batteries, a particular type of LIBs, whose main components are lithium, iron and phosphate and they will start by providing the ESS market. They will be the only company producing LFP in Europe. This

" *… means that we are not going to use cobalt, we will not use nickel. Now the ESG challenge with cobalt and nickel are very big and it takes you to country like Congo and Indonesia and into challenges like, child labour or deforestation in Indonesia. FREYR isn't exposed to that.*"

Even though they do not have specific human rights problems related to the extraction of Cobalt, from 2021 they are part of the Fair Cobalt Alliance in order to make a contribution in the development of the local economy. Nonetheless, like all LIBs producers, they need to be careful in the lithium production. Its extraction requires a big amount of water and sometimes, the impact this procedure has on the indigenous population living in the areas where these procedures are conducted, is not well known. For this reason they

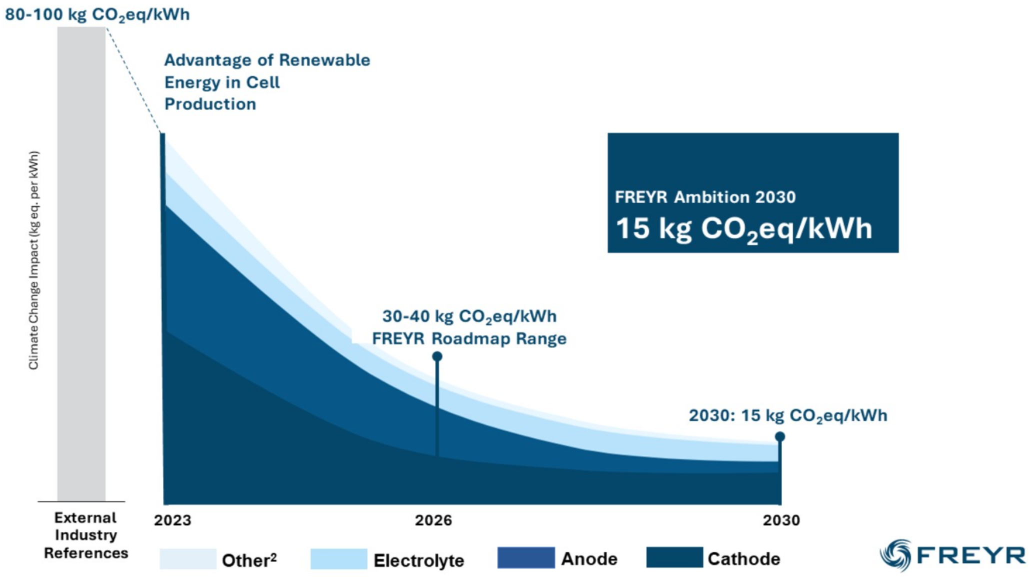
> "*... are working to get a good understanding with*" their "*suppliers on that*".

The main challenges in terms of sustainable development FREYR is facing nowadays is the reduction of carbon emissions. As mentioned by Hege Marie Norhiem:

> "*...our number one focus is carbon emissions. We are producing a product, which is meant to decarbonise transportations and grid markets, decarbonise the power sector around the world, ...from the mining, through the processing and through our factory, so cradle to gate, ...in order to deliver batteries, as we have promised, at 15kg per kW/h CO2 equivalents. Today the average is between 80 and 100 kg CO2 per kW/h equivalent and that's mainly batteries produced in China.*"

This goal should be reached by 2035 and the calculation will include just a part of the global value chain. It is a cradle to gate approach which will take into consideration the extraction, processing and manufacturing operations. Their decarbonisation path is represented by figure 13. It is very clear that in the realisation of the different components of a LFPs, especially for the anode and cathode, their CO_2 emissions will be considerably reduced within 2030, in comparison with the actual worldwide average. This will be possible thanks to collaborations with partners, sustainable oriented, belonging to different stages of the global supply chain (FREYR, s.d.).

Figure 13: FREYR's CO2 decarbonisation path



Source: FREYR, "*Our Roadmap to cut CO2 emissions in our supply chain*", s.d.

A great impact on the emissions of CO2 is given by the production of electricity. Being Norway a hydropower production country, FREYR is planning to use electricity generated by water power, cutting to zero their carbon footprint of scope 2. Indeed as mentioned before, they will rely on a hydropower supplier, Statkraft, the biggest generator of energy through renewable sources in Europe.

Another challenge the company is working on, as announced in their annual report (FREYR, 2022), is the building of gigafactories. Indeed, the impact that a company has on the local communities where the gigafactory will be built has to be positive. An important element for the success is the relationship with local stakeholders. The presence of a gigafactory in a territory can change the balance. For this reason, FREYR is creating an environment which could help the integration procedure.

> "*...we are building gigafactories in very small communities, so we are importing a lot of people and transforming small villages, ... or cities, one in Norway and one in Georgia in the US, so the impact on that local population is very important to us, so we are building houses for employees, we have to have new schools, we are*

establishing english schools for our employers, we are basically really engaging in a small town. …we have established a FREYR Academy and we will be training our own people… so that they get the knowledge needed."

Dealing with the production of batteries, means to follow specific European and International laws and standards which enable a sustainable development.

"*I think that the thing that is going to change everything is the EU Batteries Regulation, and the request for Battery Passport, as well as, the EU Corporate Sustainability Reporting Directive, ...and the European Corporate Sustainability Due Diligence Directive*"

Thanks to all these pieces of legislation, according to which companies have to make available specific data and documents, which can prove the right behaviour, transparency becomes an important aspect for a sustainable development. Indeed, companies are more and more encouraged to follow specific choices in order not to appear as non green and have more chances to attract investments. After the implementation of the IRA in the USA, the investments have shifted from Europe to the USA and this has generated some issues in the achievement of those goals that the EU had already stated. For this reason, the EU is trying to find solutions, like financial packages, in order not to undermine all their efforts till now.
One may think that all this requirements and laws can be difficult to apply but actually

"*...we are a startup, we are about to buy our software now, we are putting together the machines, we are making the contracts with the suppliers so, actually, for FREYR it is probably a good position because we can take all these regulations and implement them from the beginning.*"

The only issue is that, being FREYR a quite small company, sometimes it is difficult to stand up and be counted. For this reason, they take part in associations like EUROBAT and initiatives like the RMI, Responsible Mineral Initiative.

Despite what has been mentioned, sometimes, it is easy to bend a law. It is an example, the issue related to the guarantees of origin. They are financial documents, which are used as a means to affirm that the electricity used to manufacture batteries comes from a specific place, even though, actually, it is not like this.

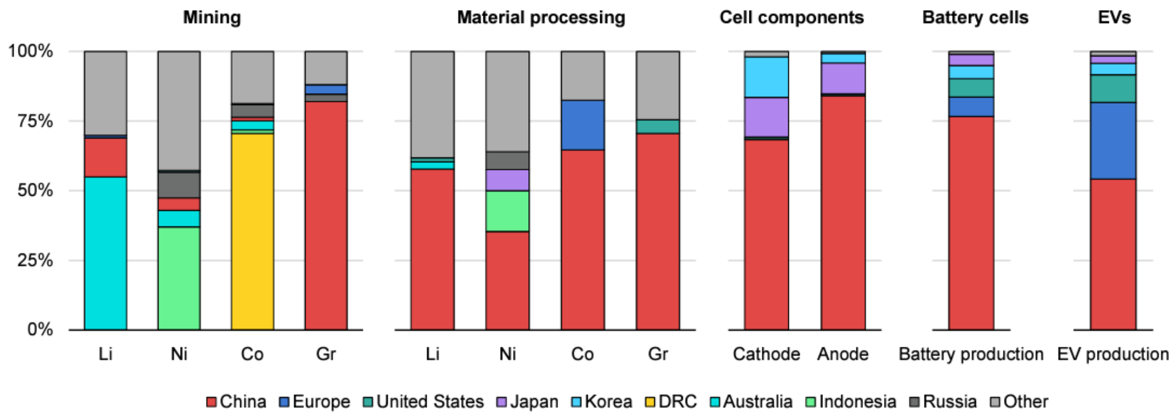
> "*We are a 100% hydro power country, there's no gas, there's no coal, it's all hydropower. But in Poland, where our competitors are producing batteries, there is no hydropower, there is almost no gas, there is almost a hundred percent coal. So, it matters to us that this producers of batteries in the EU legislation have to show that the electricity they are using, is causing a lot of emissions in the coal power station ... our competitor in Poland can buy a certificate or a guarantee of origin from Iceland for example, they also only have hydropower, ... and they can then claim that their electricity comes from Iceland.*
> *it can be used by our competitors in Poland to have totally clean scope 2. We Think that this is unfair and not true, this is basically green washing. So we are fighting very hard to have the guarantees of origin changed. And that's very important to us because otherwise we lose our competitive edge in producing hydropower in Norway.*"

This is the reason why some concern has been raised when calculating the carbon footprint of a battery.

Thanks to the type of technology that FREYR has planned to use in the production process, it is possible to reach better results in terms of sustainability, as well as, more relevant outcomes in the recycling stage (FREYR, 2022).
Nowadays, recycling batteries is an expensive activity. The more batteries you have, the more convenient it is for the operational unit which implements the procedure in terms of costs. Being the EU recycling market immature, the best option is relying on China for the recycling procedure. In this way, power units which are removed from electric vehicles, need to be sent across countries. Being batteries, dangerous goods, there are a lot of rules and laws which need to be followed for their transportation. The establishment of a business which recycles batteries from scratch in the EU, seems to be an event quite far away in time. Indeed, when

batteries are produced, they can last 15-20 years before they are recycled, but after those years, the amount of recycled material available is not sufficient to satisfy the batteries demand which has increased along the years.
Hence, it has been predicted that, starting from now, around forty years are necessary to reach the right volume of recycled material needed to fulfil the demand.
In this sense, for FREYR, this period will be even longer, indeed, being the only company producing LFP batteries in Europe, it will be more challenging to reach a considerable amount of material to be recycled and give birth to this process. Furthermore, the implementation would be even more complicated since LFP batteries do not contain cobalt, magnesium or nickel which are elements highly required in the battery market.
This strong dependency from China is not just present in the recycling stage, indeed as shown by figure 14, China scores really high in all the stages of the LIBs global supply chain.

Figure 14: Geographical distribution of the global EV battery supply chain



Source: International Energy Agency, "*Global Supply Chains of EV Batteries"*, 2022.

As a consequence, it is really difficult for companies not to interact with China. The problem is not China itself, it is the dependency from one country. For this reason, in order to avoid ESG issues, some economies have put into practice financial instruments and politics to attract activities in their countries and vary their suppliers.

4.3 Exide Technologies

With 10 production sites, 3 recycling sites in Europe and a turnover of 1.4 billion euros in 2020, Exide Technologies is a company which provides energy storage solutions for the automotive and industrial market. It started its activities 130 years ago and it has evolved and adapted its procedure to the developing market, demonstrating its dedication to environmental responsibility and innovation. Exide Technologies' commitment to sustainability goes beyond its products, it is deeply integrated in its corporate culture and governance, driving the company's efforts to be a responsible leader in the pursuit of a greener and more sustainable world (Exide Technologies, 2023).

As all the other companies which took part in this research, Exide Technologies puts a lot of attention in their sustainable development. According to Karsten Kurs, Director CSR & Governmental relations, companies which work in this sector should shape their business model, making sustainability their main focus. In order to obtain relevant results different steps need to be followed. Indeed,

> "*Process improvements and investments in efficient technologies such as waste avoidance or energy and resource efficiency contribute to greater sustainability.*
> *In this phase sustainability measures typically aim to decouple operations and environmental impacts or redesign products.*
> *Sustainable innovations reshape the core business and create new sources of income parallel to the known business.*
> *New sustainable business models create market differentiation and competitive advantages.*"

Even though the strategy is set in a proper way, the implementation in the actual world can be more difficult than what has been preset. Critical elements in this step are the top management commitment and the effective operationalization. Issues like lack of resources, also in terms of capability, which can slow down the process, often depend directly on the top management. Without the correct support, sustainable development can not be implemented in the company's processes. A good tool, which is used today, is the production of a non-financial report which is integrated in the financial one. ESG aspects, environmental, social and governance, are treated as enablers of sustainable development.

One of the main worldwide challenges, the electric automotive sector is trying to deal with, is the reduction of CO2 emissions. Thanks to the Exide's Customised Energy System, based on LIBs, the company provides, the amount of emissions and the consequent environmental impact are reduced. This is possible thanks to the integration of renewable energy (Exide Technologies, 2023). In the usage of EVs, levels of carbon dioxide released have already been lowered, so a particular attention should be put in the supply chain management.

> "*The EU Battery Regulation already provides some guidance here, but much of the supply chain is located outside EU Europe. Hence, we need to see similar efforts outside the jurisdictions of EU Europe.*"

Hence, in order to establish a common line of actions and better results in terms of worldwide sustainable development, similar measures should be taken and implemented also in countries outside of the EU, in particular in the most relevant ones: USA, India and China. As it has been analysed in the previous chapters, this latter has a strong presence in all LIBs GVC. This has not to be considered a menace, it is the normal competition which rises when a specific market starts to develop. China has this strong presence because of the first mover advantage and its competitive prices. The aspect which we should be concerned with is

> "*...whether the Chinese economic operators have the same dedication to a market that is characterised with offering a level playing field. This level playing field for a sustainable economy has to be provided by politics.*"

For instance:

> "*The EU Corporate Sustainability Due Diligence Directive applies to EU and non-EU companies, but non-EU companies of the same size than EU companies have to comply 3 years later than the EU based companies. That is not level playing field! Level playing field would require that the non-EU companies have to comply at the same date.*"

This level playing field should be established also in the EU, but actually, the Batteries Regulation gives some freedom to the member states in the implementation of more stringent measures especially for those requirements of chapter VIII.
The interviewee has been working in the battery business since 1991, so he has a lot of experience in this sector. He affirms that the implementation of the Battery Regulation is one of the most complex challenges that he has faced during his career. For a company which has operated in the energy system for so long, it is not easy to implement all the requirements of this new regulation. It implies a change in the way business is conducted. Furthermore, the lack of secondary legislation, which will be produced in the next months, makes the accomplishment of some results even more complicated. It is also important that the secondary legislation will not detach from what is written in the mandate of the Battery Regulation.

> "*...we see the risk that institutions such as the JRC try to add additional requirements beyond the mandate.*"

Thanks to the mandate, companies have already started to shape their actions and decisions according to what is demanded. If the secondary legislation would imply other requests, it is quite evident that companies would need to put more effort and it would be even more complicated to comply with the law.

Thanks to their project "New Life", which aims at recuperating materials from batteries through the recycling procedure, Exide is engaged in protecting the environment where it operates (*NewLife - Exide*, s.d.). Being the LIBs market an evolving business, it is very difficult to think about a future scenario where recycling will completely substitute the extraction of raw materials. This is due to the fact that it is really complicated to satisfy a market which is expanding, with a limited amount of material. Moreover, the design of the batteries is changing and becoming more and more innovative.
According to Karsten Kurz, the recycling process could be well implemented in EU Europe. Indeed, companies which recycle SLI and industrial batteries are already present in our continent and their infrastructures are well developed. Just in case of lack of local capacity, batteries are shipped abroad. So, actually with the increasing number of EVBs which will be

present on the market in the next year, the right approach could be to follow the already existing procedure but of course adapting and improving the infrastructures according to the future scenario set by the Batteries Regulation.

4.4 DENIOS

Denios is a company which has its headquarter in Germany and subsidiaries in Europe, USA, Canada and China. It was born as a creator of shelters, containers with special characteristics, whose aim is to contain a possible spilling of dangerous liquids and avoid big environmental issues. In this way, especially in the case of liquids which produce fire, it is possible to limit the flames inside of the shelter and give the expert enough time to intervene, avoiding environmental disasters. These shelters conduct a double function. They do not just avoid possible fires to spread, but they also avoid that an external menace could compromise what is inside of the shelters. Thanks to new technologies, it has been possible to provide the container with new mechanisms which make them even safer such as detectors of temperature, smokes and vapours. Through them, it is possible to detect eventual anomalies and intervene before something could happen.

Accidents generated by stored LIBs can attract the attention in terms of safety. They can occur because of improper storage, transportation or a lack of accurate handling, emitting a great amount of toxic gases. For this reason, starting from 2017, the company has approached the battery market, collaborating with ENEA, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile and the Italian fire department. DENIOS entered the battery market making their shelters available to store batteries while they are not used, both before and after their implementation in the electric vehicles.

In order to build shelters in compliance with the law, the European classification R.E.I. 120 is used. This means that they have been built to resist for 120 minutes under special conditions which implies high temperatures, maintaining specific standards. The aim is to try to give a safe solution to their clients.

Nowadays, there are no specific laws which deal with storage and fire management of the stationary batteries.

> "*On storage, which we are aware of, there are currently no regulations still active in Italy. But as far as I know, not even abroad.*"

“*...there are no regulations simply because today technically there are not even definitive technical solutions.*”

Having a common line of action, which means following a specific legislation, could be useful to obtain consistent results. The issue now is that the battery market is still evolving, it is not mature. Furthermore, there are a lot of players coming from different regions of the world, which took part in this process, making the achievements of such results even more complicated.
The research is studying different options to find the right answer in order to avoid possible environmental disasters with fires generated through LIBs. According to DENIOS, nowadays, the best solution to contain a fire, generated by a battery, is the use of a great amount of water. The interviewee underlighted the use of the word *contain*, since the fire of a battery can not be put out.
One of the major risks of a stored battery is the thermal runaway. Due to different conditions which could alter the normal state of a power unit, the internal temperature of a battery can increase and release all the energy accumulated. As a consequence of these electrochemical reactions, the battery cell can break and release toxic gases which could generate fires and environmental pollution. It has been noticed that the state of charge is an important element when considering stored LIBs. Indeed, a higher state of charge or an over discharged battery entail higher risk of starting a runaway in a shorter time. According to some studies, it has been demonstrated that, till now, water is the best solution to put out a fire generated by batteries (Di Bari et al., s.d.).
Due to what has been just explained, shelters built by DENIOS have been provided with tanks, which will be filled with water, as soon as the battery contained registers an anomaly. This method has the aim of isolating the problem and avoiding possible contamination with other batteries, as well as, limiting the amount of water used and disposed to manage a battery fire.
This solution could avoid or at least limit accidents like those which happened on cargo ships in the last years, for instance. Usually, batteries or cars, which are carried around the globe, can remain for some days inside of containers without any control, for this reason the probability of contracting an accident is higher. These events have strong economic and financial effects, in addition to the environmental ones. In the last five years, compensations

owed because of explosions or fires, counted for 18% of the overall compensations (De Forcade, 2022).

4.5 Conclusion

This chapter presented the findings obtained using a qualitative method, through direct and indirect semi structured interviews. The aim was to highlight the company's point of view. For this reason, to have a better overview of the phenomenon, it has been decided to contact businesses conducting their activities along the all LIBs GVC. Information obtained has been supported by documents which help in giving reliabilities to what has been presented. Some similarities especially in terms of European Union legislation have been found, as well as some differences. Results will be discussed in the next chapter.

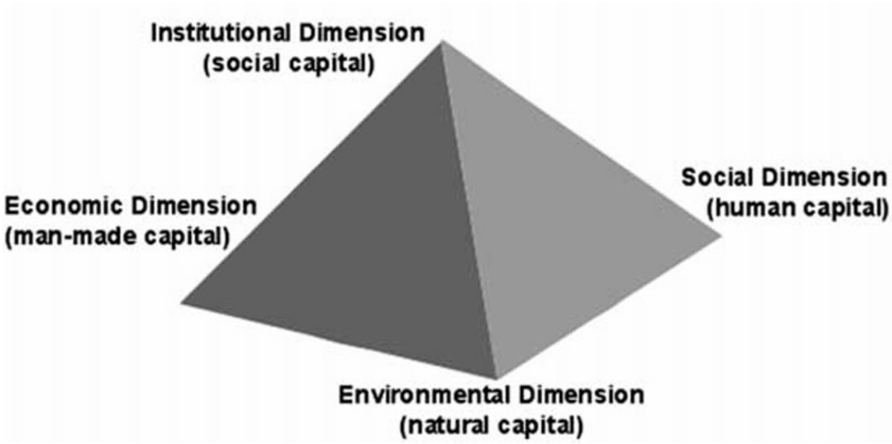
CHAPTER 5
DISCUSSION OF THE RESULTS

This chapter is the final stage of the research conducted. It will present a discussion on the results obtained in the previous chapter, with the aim of showing an understanding of the enablers and barriers for a sustainable development in the LIBs GVC and the position adopted by the EU. The intention is to provide a picture of the current state of the LIBs GVC, through the application of the sustainable development concept, offering an insight of the potential pathways that the EU can explore in order to exploit opportunities presented by this sector.
The outcomes of the discussion are expected to also inform future policies and decisions, in the global energy and technology market.
As already explained in the previous chapters, results obtained can not be generalised as for those which are usually obtained through a quantitative analysis.

5.1 The concept of sustainable development

The industrial and social growth, which occurred in the last twenty years, generated important effects on the ecosystem and economies of the world. As a consequence, the concept of sustainable development rose (Estevez & Janowski, 2013). Brundtland (1987) defines it like the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".
Even though companies around the world are implementing strategies for sustainable development, sometimes it is not easy to realise it, there are challenges to face in order to perform sustainable actions.
As explained by Estevez & Janowski (2013), there are five principles which define sustainable development: the reduction of poverty, the generational equity, the integration of environmental policies, the involvement of local communities in setting decisions, and facing environmental and technological issues while growing.
In order to better represent the concept of sustainable development, along the years, different models have been created. This research will consider the one denominated **Prism of Sustainability Model** (figure 15) (Keiner, 2005).

Figure 15: The prism of sustainable development



Source: Keiner, "History, definition (s) and models of sustainable development", 2005.

This representation, developed by the German Wuppertal school, is an implementation of the basic one called the "three pillar", where the institutional dimension was not taken into consideration.

The Prism of Sustainability Model analyses four fields of interest: the economic, the environmental, the social and the institutional dimension. Sustainable development can be achieved, just focusing at the same time on all these four aspects (Keiner, 2005).

Each area is defined by different characteristics. The economical one considers all the material goods created by the human being. It tries to find a balance between the economic growth, resource management and concern in the environmental impact; this could generate value in the future. The environmental dimension analyses the renewable and nonrenewable resources which create natural capital. Responsible consumption of resources in order to avoid waste, biodiversity preservation, transition towards the electric and circular economy are important practices, to achieve good results in this field. The social dimension examines consciousness in terms of the subject knowledge and experience, it entails principles of equity, inclusivity which are sustained by the respect of human rights, societal justice and protection of diversity and equal opportunities. Lastly, the structure of the society and the connection among individuals are treated by the legislative dimension (Keiner, 2005; Procter and Gamble, 2023).

5.2 Discussion

Batteries have been introduced in the market as a valid alternative to fossil fuel. However, they present positive and negative aspects, as well as criticality, which will be discussed thanks to the help of our case studies.

From one side, batteries are an ecological and sustainable solution, both in the transport and storage sectors, reducing the emissions of GHG and fostering a CO2 low emissions future. On the other hand, issues like the energy efficiency, supply of raw materials, waste management, risk connected to their safety and legislative inconsistency are critical aspects which are worthy to be taken into consideration.

In the next paragraphs, by applying the concept of sustainable development, we will try to find an answer to our research question, making a comparison between the different case studies previously analysed.

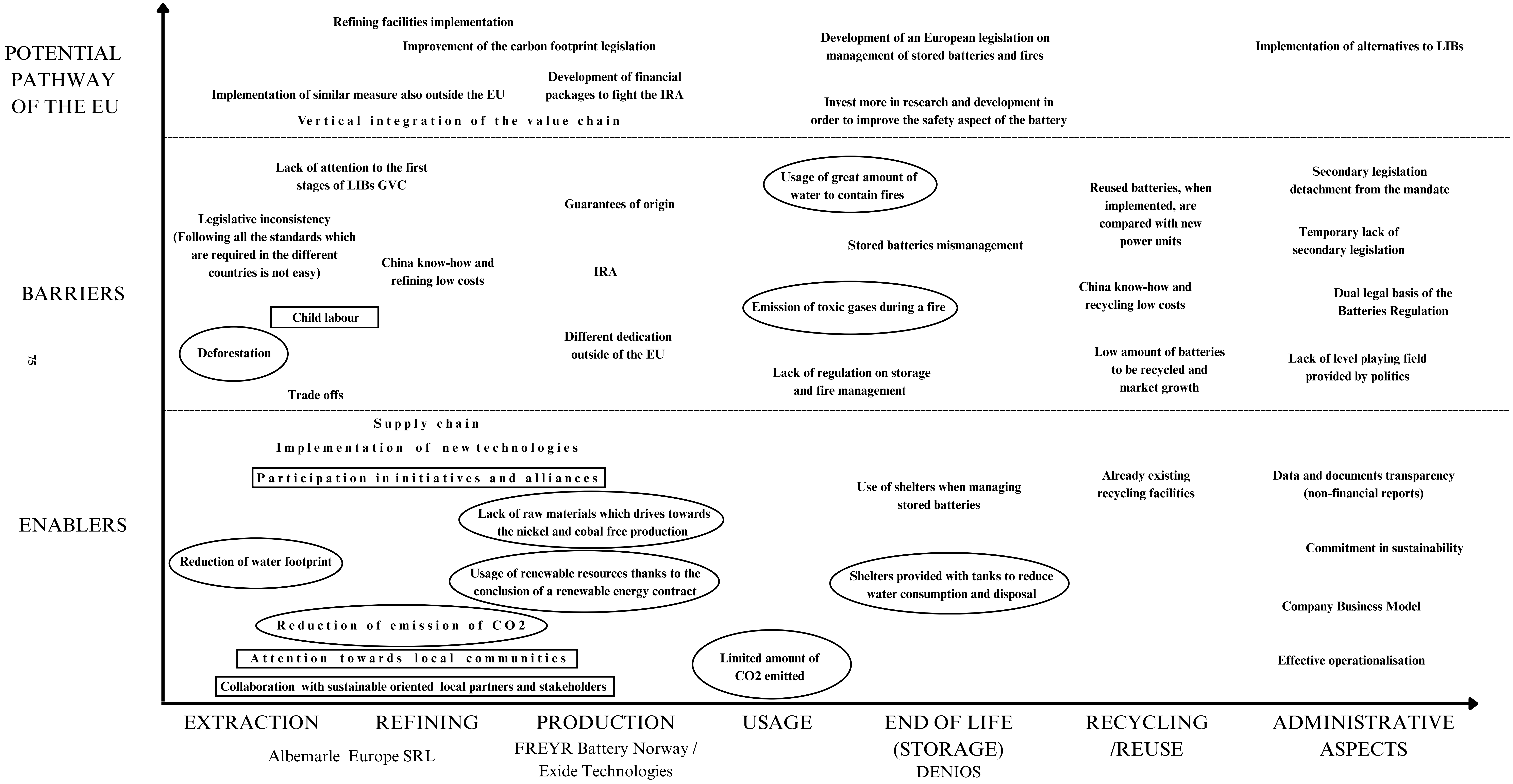
5.2.1 General overview of barriers and enablers of the LIBs GVC

In order to give a graphic explanation to our discussion, the graph represented in figure 16 has been realised.

The image is a cartesian plane, which aims at allocating the results of the research previously conducted, by grouping them into two sections, the enablers and the barriers towards sustainable development along the LIBs GVC. Moreover, thanks to the graphical representation, it is possible to identify the potential pathways that the EU can explore along the GVC, in order to fill those legislative gaps highlighted by the interviewers.

According to what explained in the sustainable development paragraph, in the graph, elements which belong to the environmental areas have been circled, whereas those acting in the social sphere have been boxed.

Figure 16: Conceptual overview of the discussion


POTENTIAL PATHWAY OF THE EU
Refining facilities implementation
Improvement of the carbon footprint legislation
Implementation of similar measure also outside the EU
Development of financial packages to fight the IRA
Vertical integration of the value chain
Development of an European legislation on management of stored batteries and fires
Invest more in research and development in order to improve the safety aspect of the battery
Implementation of alternatives to LIBs
BARRIERS
Lack of attention to the first stages of LIBs GVC
Legislative inconsistency (Following all the standards which are required in the different countries is not easy)
China know-how and refining low costs
Child labour
Deforestation
Trade offs
Guarantees of origin
IRA
Different dedication outside of the EU
Usage of great amount of water to contain fires
Stored batteries mismanagement
Emission of toxic gases during a fire
Lack of regulation on storage and fire management
Reused batteries, when implemented, are compared with new power units
China know-how and recycling low costs
Low amount of batteries to be recycled and market growth
Secondary legislation detachment from the mandate
Temporary lack of secondary legislation
Dual legal basis of the Batteries Regulation
Lack of level playing field provided by politics
ENABLERS
Supply chain
Implementation of new technologies
Participation in initiatives and alliances
Lack of raw materials which drives towards the nickel and cobal free production
Reduction of water footprint
Usage of renewable resources thanks to the conclusion of a renewable energy contract
Reduction of emission of CO2
Attention towards local communities
Collaboration with sustainable oriented local partners and stakeholders
Limited amount of CO2 emitted
Use of shelters when managing stored batteries
Shelters provided with tanks to reduce water consumption and disposal
Already existing recycling facilities
Data and documents transparency (non-financial reports)
Commitment in sustainability
Company Business Model
Effective operationalisation
EXTRACTION
Albemarle Europe SRL
REFINING
PRODUCTION
FREYR Battery Norway / Exide Technologies
USAGE
END OF LIFE (STORAGE)
DENIOS
RECYCLING /REUSE
ADMINISTRATIVE ASPECTS

5.2.1.1 Enablers for sustainable development

As it is possible to observe, the first steps of the LIBs GVC are the most critical, especially from an environmental and social perspective.

A factor, which has been defined as critical for the achievement of sustainable results, is the *supply chain*. Notably from an environmental perspective, this element has a big impact on the final outcomes. Companies which operate in the extraction, refining and production stages, like Albemarle, FREYR and Exide Technologies, are more and more careful regarding their strategic decisions in the achievement of their goals. Hence, suppliers that are sustainable oriented, are preferred compared to those which are not in line with the company's values.

For instance, when a company is involved in a purchasing activity, the selection of the suppliers becomes an important factor. Compliance with the law and with sustainable criteria, which could affect the final environmental footprint of the company, as well as available information on the supplier, become determining factors (Pimenta & Ball, 2015). For these reasons, choosing the right suppliers can drive towards a more integrated sustainable activity.

The reduction of CO2 is a thorny theme, especially when dealing with supply chains. As already explained, the emissions caused by suppliers can have a relevant impact on the carbon footprint. This aspect is also important during the conduction of the activity the business is concerned with. Indeed, the reduction of CO2 emissions is essential to achieve sustainable results. Companies rely on different solutions. For instance, Albemarle has implemented photovoltaic facilities and concluded renewable energy contracts, FREYR production will be hydropower, thanks to a collaboration with Statkraft, Exide Technologies, through its Customised Energy System, has implemented an energy solution based on renewable sources as well. Hence, renewable energy becomes the key element for the reduction of CO2 emissions, especially in the first stages of the GVC.

Another important aspect, related to the environmental field of action is water consumption. This issue has been highlighted especially by Albemarle, in the extraction of lithium. Companies are studying alternatives in order to reduce the amount of water used during the extraction and refining activities. Thanks to the implementation of new technologies, it has been possible to introduce new solutions like direct lithium extraction, always paying attention to the environmental impact. FREYR has underlined that the water footprint of an extractor of raw materials, like lithium, is an important variable when selecting suppliers of materials needed to produce cells.

Moving in the production stage, a crucial element, also discussed in the literature review, is the criticality of raw materials. It is interesting to see how this problem has stimulated the creation of activities like the one of FREYR, where efforts are allocated in a cobalt and nickel free production, pursuing sustainable objectives.

As already presented in the literature review chapter, during the usage of EVs, the amount of CO2 emitted is limited compared to the same stage in fossil fuel vehicles. This is one of the main reasons why the electric has been chosen as a valid substitute for current cars. Once batteries come to their end of life, they need to be removed from the vehicle and stored before being recycled or reused. Stored batteries management is a critical stage of the LIBs GVC. The use of shelters, specially created for this activity, can reduce the environmental impact of possible disasters. When a fire takes place a great amount of water is needed to contain them, DENIOS provides an alternative which implies a reduced quantity of water.

Thanks to the sustainable development idea, the concept of circular economy has taken hold in the market. The recycling stage is the key point which enables the concretization of this phenomenon.

Through this procedure, it is possible to recuperate critical and essential elements like lithium, cobalt and nickel and reintegrate them into the market. Even though this process probably would never substitute the extraction of raw materials, it could contribute in a consistent way to its provision, ensuring security of supply. Nowadays, in the EU, this process is still not well developed for EVBs, because of the immaturity of the market and the lack of a consistent amount of material needed to put into action the procedure by breaking down the costs. This is the reason why the EU is now relying on foreign countries for their recycling. In this perspective, our research highlighted two different opinions.

According to Albemarle and FREYR, which share the same point of view, the recycling of EVBs, in the EU, is a process which could be conducted almost independently not before 2040, when the amount of recycled material is expected to be consistent. Indeed, batteries which are put on the market have a useful life of almost 15-20, considering also the second usage. Hence, they come to the disposal stage after a long period. Being the battery market quite young in Europe, the power unit already sold on the market still has not reached the disposal stage.

On the other side, Exide Technologies has a more optimistic view, indeed, according to what was discussed during the interview, the recycling process could be well implemented in EU Europe. Indeed, SLI and industrial batteries are already recycled in our market, so the right approach could be improving and adapting the already existing infrastructures, according to the increasing economy.

Taking into consideration the social dimension, fundamental in the first stages of the GVC, in order to pursue a line of action towards a sustainable development is, as explained by Albemarle and FREYR, the attention towards local communities where the activity is conducted. Here, relations with local stakeholders are essential. They can have a significant impact on the activity and on the achievement of companies' sustainability goals, with a consequent effect on the final outcomes. In this case, participation in initiatives and alliances, like the IRMA for Albemarle, or the RMI and the Fair Cobalt Alliance for FREYR, can make the difference and help the company in elaborating specific actions to achieve even better sustainable results.

When analysing the administrative section, as discussed by Exide Technologies, in order to conduct an activity which is aimed at sustainability, particular attention should be given to the company business model. Sustainability should not be just a goal to be reached, it has to be an intrinsic element of the company, it should be the key point of each decision. In other words, sustainability should be the core of the company business model.

In the implementation of the strategy set by the guidelines of the business model, important is the commitment of those people who are at the top management, in order to pursue a common line of action towards a sustainable development. Lack of resources, also in terms of capabilities can represent a barrier.

When companies operate in a market where sustainable development is the driving force, concrete results need to be provided. In the last few years, the non-financial report has been introduced as a new tool, which makes available considerable results from an environmental, social and governance angle, in relation to the activities developed by the company. This report provides transparency, which is a key factor for sustainable development.

5.2.1.2 Barriers of sustainable developments

The implementation of actions towards sustainable development is not always easy. As analysed in the previous chapter there are some elements and dynamics which prevent this result to be achieved. This subparagraph has the aim of presenting and discussing them.

According to the field of interest of the different companies which were interviewed, diverse barriers have been found along the LIBs GVC, as shown by figure 16.

The first element, discussed by Albemarle in the extraction stage, but which could be extended to all the stages of the value chain, is the presence of trade-offs when conducting a business. Developing an activity means facing different opportunities every day. Decisions which are taken should always be oriented towards sustainability, but sometimes, this is not easy. The investment of efforts to make an action more sustainable, from one side, can imply the creation of unsustainable outcomes elsewhere. An example, the extraction of lithium through a new technique which avoids the evaporation of water in the brines, the issue is that it requires using much more freshwater than the usual procedure.

Always in the extraction stage, taking into consideration the environmental dimension of the Prism of Sustainability Model, an important barrier has been introduced by FREYR. Among the list of critical raw materials presented by the Critical Raw Materials Act, discussed in chapter 2, nickel is one of them. Due to the dream of the Indonesian government to become the major extractor of nickel in the world, deforestation activities started to catch on, destroying huge green areas (Naryono, 2023).

Moving on the social dimension instead, the attention shifts to DRC where in the extraction of cobalt, child labour is a quite common practice. This can be considered as a barrier towards sustainable development, since human rights are not respected.

In addition to these environmental and social barriers, important is the role of the legislative aspect. Legislative inconsistency has been underlined by all the companies interviewed, in different moments along the LIBs GVC. According to Albemarle and FREYR, this element is embodied in the carbon footprint requirements and calculation. Indeed, the already existing legislation does not provide a sufficiently clear policy to be applied, without creating misunderstandings and setting precedents. An example, the guarantee of origin mechanism, claimed by FREYR, which enables countries to declare some statements, in relation to their carbon footprint, making them appear as sustainable, when this does not match the reality.

This turns the spotlight on the important role that politics have. An example is the implementation of the EU Corporate Sustainability Due Diligence Directive, as underlined by Exide Technologies, which requires different implementation terms, according to the affiliation of a country to the EU or not. This different level playing field generates a sort of discrimination among countries, which could give birth to not fair behaviours, or lead companies to develop their activities outside the EU.

This is what happened with the IRA, where investments have moved from the EU to the USA because of the incentives provided. According to FREYR and Albemarle, this practice has slowed down the achievement of the environmental goals, set by the EU, in relation to the development of new battery technologies. The EU is working in order to stop this phenomenon by creating financial packages which could attract new investments.

Another important aspect, stressed by Albemarle, when considering barriers for a sustainable development, is the lack of attention at the extraction and refining procedures, in the EU. As a consequence, these processes are conducted abroad where know-how and low costs create an attractive environment. This makes sense for the extraction, since Europe is scarce geologically talking, but refining facilities could be implemented. This would avoid the importation of refined materials from abroad, which generates environmental and economical costs and dependency from foreign countries. Here, the problem is whether the procedures conducted abroad follow the same standards and criteria for environmental and social sustainability, as the ones stated in the EU.

Moving forward on the GVC, other issues can be underlined. For instance, during the usage and the storage of LIBs there is a quite high risk of fire generation, when the battery is subjected to mismanagement or different environmental conditions. This could cause the release of toxic gases, endangering the surrounding environment. As explained by DENIOS, nowadays, the only way to contain a fire is the usage of a great amount of water, which is not an eco-friendly behaviour, since water is one of the elements considered critical for humanity. Furthermore, when it is used in cases like this, it needs to be purified from those elements which prevent it from being released in nature.

DENIOS affirmed that, nowadays, there is not any European legislation which rules this procedure. This is probably because of the absence of technical solutions, due to the immaturity of the scientific research of this LIBs GVC stage. Even though the Batteries

Regulation has improved the legislative environment of electric batteries, the fires and stored batteries management is still an aspect which needs to be reviewed and made more consistent.
The second life and especially the recycling of batteries have been presented as the key points for sustainable development. Despite this, there are some comments worthy to be made. The second life requires the implementation of a battery, which has already been employed in a car, in alternative solutions like the storage systems, when the battery has already reached 90% of its lifetime. This means that the power unit does not have the same power of a new one. Hence, if we consider a future scenario, where a second life battery is implemented, not just in the storage system, but also in less powerful vehicles, a problem can be highlighted. The already used battery needs to be compared with new ones on the market with innovative technology, new materials, and better performances. Hence, this could generate a sort of scepticism from the purchaser's point of view. This aspect could be mitigated through the provision of documents, like the Battery Passport, which could grant the quality and safe parameters of the battery, providing transparency.
When considering the recycling procedure, nowadays for EVBs the EU relies on China. This is because, as explained in the previous subparagraph, Europe still does not have enough batteries to conduct the process by breaking down costs. Furthermore, being China the first country that has implemented this procedure, it has a know-how which can not be compared to the one of the EU.
Finally, the administrative aspect puts the attention on the Batteries Regulation. This piece of legislation is the most innovative in terms of EVBs and it is the first product specific legislation, for batteries, ever produced. It will be implemented under the secondary legislation and it sets the environment for the future of EVB. Despite this, the difficulty of implementing this piece of legislation came to light. Exide Technologies highlighted that the absence of a secondary legislation, which is not ready yet, could generate the intervention of some institutions, which could propose additional requirements, creating a detachment from the mandate, making the implementation for companies even more complicated. Furthermore, the dual legal basis condition, based on article 114 of the Treaty on the Functioning of the European Union (TFEU), and Article 192(1), related to rules on the end-of-life management of batteries (Halleux, 2023) and the right of the Member States of implementing more stringent measures, create a situation of different level playing field among countries, which prevent the homogeneous achievement of sustainable results.

5.2.2 Potential pathways of the EU

Thanks to the explanation of the enablers, but in particular of the barriers towards a sustainable development in the LIBs GVC, it has been possible to define some areas of interest, where the action of the institutions of the EU, through the generation of new legislation, or the modification of the already existing ones, could improve the current policy.

One of the first aspects which could be revised, is the carbon footprint legislation. According to our interviewers, the already existing one presents legislative inconsistency. An example, the guarantee of origin method. It could be possible to define even better the requirements for the carbon footprint, which could be implemented by rewarding companies which conduct their business in the EU, producing in a more sustainable way.

Another important legislative gap, which has been discussed, is the lack of a legislation which rules the management of stored batteries and fires. This gap is mainly caused by the absence of technical solutions proved by scientific research.

Lastly, it has been noticed that the different powers in the world such as the USA, China, Europe etc. are on different development levels of the transition towards an electrified future. In these terms, a global legislation, which could require the same measures around the world, would be an important result towards sustainable development.

From an industrial point of view, some of the already explained environmental, social and economical problems in the LIBs GVC, can find a possible solution in this thesis.

According to what explained in the previous subparagraphs, it is also possible to highlight future strategies that businesses, which operate in the battery sector, could implement, in order to cope with LIBs GVC issues. For instance, in terms of sustainability, companies should set their strategies focusing their attention on their environmental and societal impact in the area where they operate. They could implement more sustainable activities, reducing the emission of CO2, by relying on renewable resources and making contracts with right partners. This could contribute in the run towards the minimization of CO2 emissions. Fundamental, the respect of the society of the area of interest by considering their opinions before acting.

In order to reduce even more the environmental impact companies could provide recycling service. In these terms a vertical integration of the value chain could be seen as an important opportunity for a business which wants to be more independent. Producing not just cells but

also materials, electrical components and thermal management systems, and conducting activities like recycling, would be a value added for the company.
Moreover, industries could invest more in research and development in order to improve the safety aspect of the battery, which has been proved to be not yet considered enough. This means building new production technologies or new cell architectures. Furthermore, the usage of shelters, like the one of DENIOS, in specific conditions, when batteries are not used, could limit environmental disasters.
As reported by our study, the refining market is almost absent in the EU, this could be an interesting opportunity for companies which want to approach the European battery market and exploit those areas of interest not yet developed. This would be possible, just if the European institutions will help from an economical point of view those businesses interested. Indeed the costs of refining facilities implementation in Europe are still too high to break down the foreign competition.
Another important issue of the LIBs GVC is the scarcity of raw materials, used to create batteries. They also entails problems like deforestation and child labour, previously mentioned. This can stimulate businesses in adapting their production to new types of batteries, which imply a reduced amount of critical raw materials such as nickel, cobalt, like the LFP batteries produced by FREYR. Despite this, being lithium LIBs fundamental component, and one of the critical raw materials listed in the Critical Raw Materials Act, it is not possible to avoid using it. This is the reason why alternative solutions to LIBs have been promoted on the market. For instance, as presented in the second chapter, hydrogen cars have been implemented. These vehicles do not affect the market of critical raw materials, they cut to zero their emissions while using and they have good performances which could be compared to the ones of the conventional cars. Unfortunately, a great amount of energy is required to generate hydrogen and this element is quite sensitive to be treated.
Other solutions like sodium-ion batteries have been proposed. They work in the same way as LIBs, but actually, sodium is highly available on our planet, more than lithium, and its cost of production is lower. Furthermore, sodium-ion batteries are safer, due to their higher temperature range, compared to lithium, as a consequence they are less subjected to explosions and they have a less environmental impact. Despite this, its handling needs specific conditions which do not imply moisture, otherwise it could affect the final results, moreover they have a less long lasting life-cycle and they are less efficient in terms of

performances. This is the reason why their implementation is suggested in the storage systems but not yet in the EVs (Flash Battery, 2023; Slater et al., 2013).
As it is possible to notice, all the alternatives provided to substitute fossil fueled cars, like LIBs, sodium-ion batteries and hydrogen powered cars, present both positive and negative aspects. As mentioned by Francesco Gattiglio, it is always a matter of trade-offs. This is the reason why, all these alternatives seem to be just temporaries and not definitives. From an environmental point of view, if considering just emissions of CO2, all the solutions presented have better performances compared to the conventional cars, but there are always other economical, environmental, legislative and societal aspects which need to be considered.

5.3 Conclusion

Thanks to the discussion of the results obtained through the research presented in the previous chapter, it has been possible to compare companies points of view on positive and negative aspects of the LIBs GVC towards sustainable development. Emphasising environmental and societal issues, thanks to the application of the sustainable development concept, it has been possible to suggest possible future actions in an industrial and legislative European perspective, as well as globally. Unfortunately, being the battery market still evolving, there are some aspects which we can not find a definitive answer to. For instance, how to improve the safety of electric batteries, reducing the risk of fires and related problems, when the recycling procedure will be effectively implemented in the European market or whether the LIBs could be really the future of private transports.
These are all interrogatives at which it could be possible to find a solution just waiting and seeing.
To conclude, we should not forget that the EVB market is evolving every day, hence, there will always be new challenges and issues with the passing of the time.

CHAPTER 6
CONCLUDING REMARKS

This thesis conducted an examination of the LIBs GVC, highlighting the enablers and barriers which shape this industry.

The findings of this research could serve as a foundation for policy makers, industry leaders and researchers to make informed decisions and strategic investments.

After a general introduction of the GVC concept and a deep examination of the LIBs GVC, where environmental and social issues have been highlighted, a thorough research has been conducted, to find an answer to the research question. In order to have a better overview of the GVC industry point of view, companies conducting their activities, along different steps of the LIBs GVC, have been selected.

Thanks to a qualitative approach, based on a multiple case studies analysis, it has been possible to present interesting results.

It has been noticed that, from an environmental and societal point of view, the most critical moments along the LIBs GVC are the extraction, refining and production stages. Supply chain has been discovered to be a crucial element for the companies. For instance, the selection of the suppliers becomes an important factor for the final outcomes, as well as collaboration with local partners. This aspect is strongly affected by CO_2 emissions and water consumption which need to be considered. In this context, in the carbon footprint legislation, legislative inconsistency has been pointed out. A clearer definition of the carbon footprint requirements would be appreciated. From an industrial perspective, the implementation of CO_2 emissions reduction practices, like the reliance on renewable resources or the implementation of the recycling procedure, will enable the companies in achieving better sustainable results.

Moreover, volatility of the market because of the criticality of raw materials, in the last few years has become one of the major issues of the LIBs GVC. This has created concern in some industries, which have started implementing alternatives, which do not imply the usage of some critical materials like nickel and cobalt, avoiding issues related to the environmental and societal spheres.

Another interesting consideration has been made in terms of management of stored batteries and fires caused by them. The legislative gap in this area, probably owing to the absence of technical solutions, suggests that the industry sector should invest in the research and development department to find sustainable solutions. For instance, building new production technologies or new cell architectures could be a possibility.

Furthermore, the absence of a refining market in the European Union gives the opportunity to approach the European battery market and exploit this area of interest not yet developed.

Considering all the problems of the LIBs GVC, discussed in the previous chapters, some alternatives solutions, like hydrogen powered cars or sodium-ion batteries, have been taken into consideration. Even though their sustainable footprint is strongly visible from the reduction of emissions perspective, there are other economical, environmental, legislative and societal aspects which need to be considered.

Lastly from a legislative and industrial development point of view, the different parts of the world are experiencing different moments. This opens a perspective towards the development of a more homogeneous worldwide legislation in terms of batteries and sustainable development.

To conclude, all these considerations have been done on data and information available now, but the battery market is evolving and adapting with the past of the time. Hence, some interrogatives like whether the LIBs will be the future of the automotive industry, can find their answers just waiting for the evolution of the market.

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LEGISLATIONS

(Batteries Regulation)
REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/89/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (2023) (European Union)

(Critical Raw Materials Act)
REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, Regulation n. COM 160/2023 (2023) (European Union). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0160

(High risk third countries)
Commission Delegated Regulation (EU) 2023/410 of 19 December 2022 amending Delegated Regulation (EU) 2016/1675 as regards adding the Democratic Republic of the Congo, Gibraltar, Mozambique, Tanzania and the United Arab Emirates to Table I of the Annex to Delegated Regulation (EU) 2016/1675 and deleting Nicaragua, Pakistan and Zimbabwe from that table (Text with EEA relevance)
https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32023R0410#d1e32-7-1

(Proposal for the Batteries Regulation)
Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, Regulation n. COM 798/2020 (2020) (European Union).
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