REVIEW OF LEGAL REQUIREMENTS RELATED TO EXTENDED PRODUCER RESPONSIBILITY OF LITHIUM BATTERIES IN GERMANY, FRANCE, AND SPAIN

Lappeenranta–Lahti University of Technology LUT

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Post-doctoral researcher, D.Sc. (Tech) Kaisa Grönman

ABSTRACT

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ABSTRACT

The inclusion of batteries and accumulators in the market improved the increase of electronic devices use, mobility, convenience, and reduction of fossil fuel motors in society. Among the batteries, lithium-ion is currently the best solution due to the energy capacity, chargeability, and scalability. In 2030 the rate of lithium-ion batteries (LIB) production capacity will be fifty times bigger than in 2020 and this is highly influenced by the use of LIB in electronic vehicles (EVs). However, the future of batteries in still unclear because of the lack of raw material and its end-of-life management. To solve this challenge, policies regarding reuse, refurbishment, and recycling of LIB are being developed to guarantee longer life to batteries and the reuse of minerals, as lithium, cobalt, and nickel to produce new items. As part of policies, the extended producer responsibility (EPR) is a crucial point to guarantee circularity for batteries. This study has the goal to analyse the EPR in Europe, mainly Germany, France, and Spain, regarding LIB management, logistics, and recycling

ratios. Since the three countries are part of European Union (EU) and United Nations (UN), many policies, mainly for logistics and recycling rates, are defined by this country partnership, which makes simpler the process of transboundary operations and standardization of waste code and definitions. On the other hand, each nation has also specific regulations or authority's systems that must be considered to manage LIB. Currently EU is in process to approve a new regulation for batteries and this will influence all the member countries to review its specific regulations and supervision to guarantee a convergent policy for LIB and improve circularity of this type of item and its metal parts.

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Abbreviations

ADR	Agreement concerning the International Carriage of Dangerous Goods by Road
ARF	Advanced Recycling Fee
B2B	Business to business
B2C	Business to consumer
BSD	Bordereau de suivi des déchets
CE	Circular Economy
CMR	Convention relative au contrat de transport international de marchandises par route
EEE	Electrical and electronics equipment
EoL	End-of-life
EVs	Electronic Vehicle
EU	European Union
EPR	Extended Producer Responsibility
DSR	Deposit refund system
LCO	Lithium Cobalt Oxide
LIB	Lithium-Ion Batteries
LMO	Lithium Manganese Oxide
SDG	Sustainable Development Goals
SIRET	Système d'identification du répertoire des établissements
UN	United Nations

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1. Introduction

The development of technology in the world is transforming our society more digitalized and dependent of electricity. Because of convenience, energy storage and decarbonization, the use of accumulators is in a high increase and today the lithium-ion technology is the fastest growing and most promising battery chemistry (Battery University, 2017). According to Persistence Market Research (2021) the market size of lithium-ion batteries (LIB) in Europe was estimated to record 12.9% growth in 2021 compared to 2020. In Europe, another current situation that is boosting the use of batteries is the energy crisis (Breton, 2021). According to the International Energy Agency, the consume of energy in 2021 increased 5% (International Energy Agency, 2021).

LIB has been in the market with considerable volume since 2010 and the management of end-of-life (EOL) items is a topic that is still a challenge. In Italy, for example, LIB market share of battery's market increased from 11% to 25% between 2014 and 2019. (Giosuè et al., 2021) Moreover, the lack of recycling and refurbishment facilities and a complex regulation that involves different stakeholders in each country increases this challenge. This thesis aims to identify the legal obligations related to extend producer responsibility (EPR), transport and recycling in France, Germany, and Spain.

Most part of the studies related to lithium-batteries end-of-life management are focused on treatment technologies, but there are few approaches related to the regulations related to it. An interesting article published by Melin et al. (2021) brings an approach for the European Union (EU) and countries differences. As Huo et al. (2017) also comment, the transportation regulations are not aligned between countries and national regulations are different of international regulations. Furthermore, Bird et al. (2022) also presents an interesting view related to the EPR and recycling regulations.

Apart from EU regulations, each country has different regulations for EoL of lithium-ion battery and because of the lack of capacity for recycling this material, it is crucial to understand the regulations of the countries and possibilities of transboundary operations.

1.1. Background of the study

A short background study of EPR and Circular Economy was carried out to bring some current context of LIB end-of-life management promotion awareness.

1.1.1. Extended producer responsibility

EPR is an environmental policy that defines producer's responsibilities to the end of life of its products. The extended producer responsibility concept has been established as the main environmental policy in countries part of Organisation for Economic Co-operation and Development (OECD) since the late-1980s (Gupt & Sahay, 2015 and OECD, 2016) .

According to the OECD (2001), principles of EPR is financial and/or physical regarding the treatment or disposal of post-consumer products, based on shifting the responsibility to producer instead of municipalities and to incentives producers to consider environmental aspects when design products.

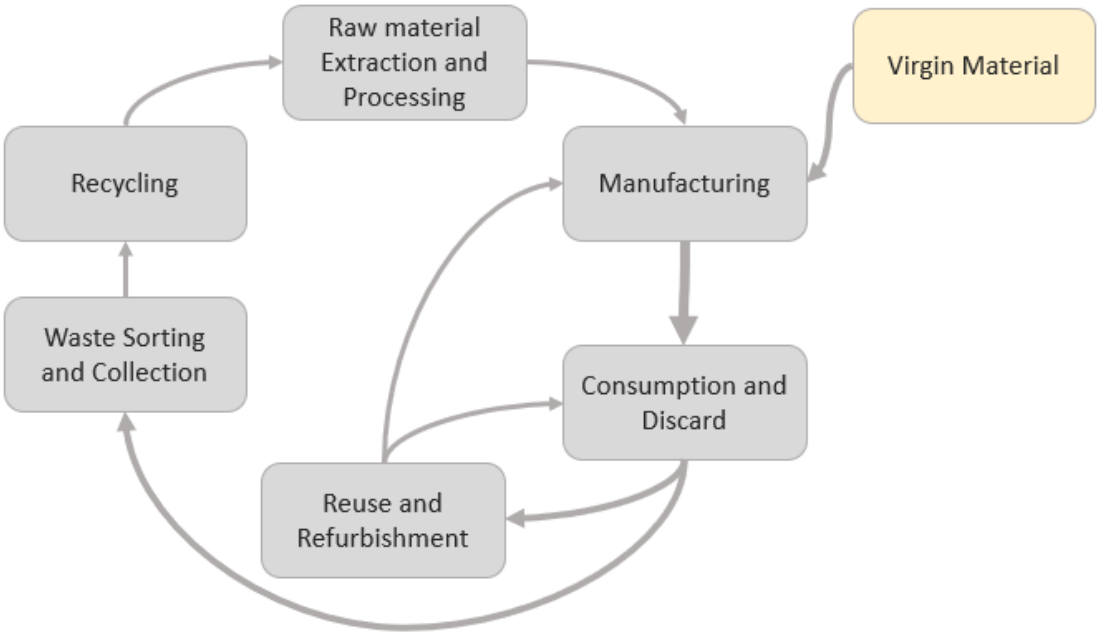

Figure 1 *EPR: stages of a product life cycle.*

Based on the guidelines of EPR, lithium battery producers need to provide second life solutions or recycling alternatives for closing the loop of raw material (Figure 1).

In countries of Europe, the EPR are usually split into two layers of regulations: the EU regulations and the country regulations. In some countries, a third layer exists based on each state regulation for waste sorting, transportation, and treatment.

1.1.2. Circular economy potential and relation to the SDGs

Sustainability is a term presented during the eighties in the Brundtland report that proposes a balanced relationship between society, environment, and economy. Based on it, during the last decades innovative approaches were presented to improve our sustainability. Among all the approaches, Circular Economy is one that was well accepted by society and started to be intensively discussed since the 2010s.

Circular economy is the idea to change our economic model from linear, extraction, production, use and discard, to a closed loop where the materials are ways include in a new loop, so it has no end (Figure 2).

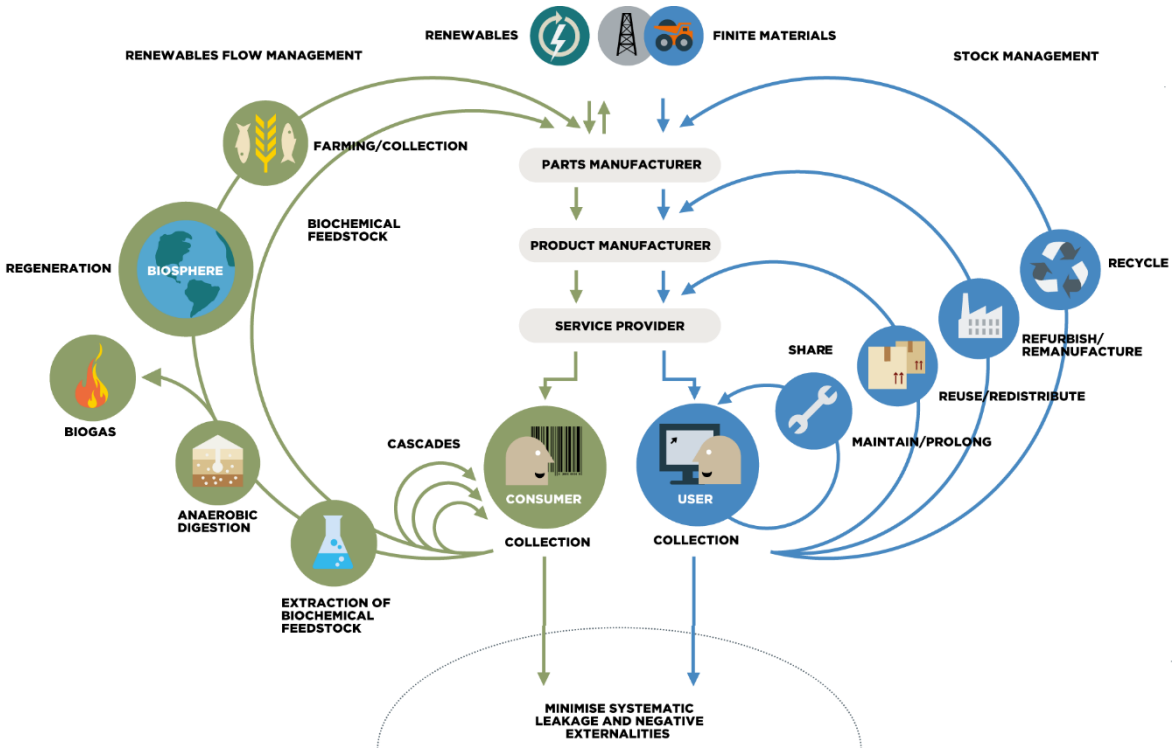

Figure 2 *Circular economy systems diagram* (Ellen MacArthur Foundation, 2019)

Aligned with the idea to close the loop, the regulations regarding the recycling of LIB support and motivate EPR to give better destinations of end-of-life items. These regulations

are made and supported by all levels of society, from the cities to the United Nations (UN) moving towards a more sustainable world.

In the last decade, to make the sustainability approach more tangible in an agenda until 2030, the United Nations decided to define clear goals based on seventeen streams that were named the Sustainable Developments Goals (SDG). For each of the streams, the UN defined targets and indicators that support the validation of the actions of society and our level of sustainability (Figure 3).

Figure 3 *The 17 Sustainable Developments Goals defined by United Nations.* (United Nations, 2015)

Based on the 17 SDG, the topic of LIB and managing the end-of-life items are related to at least four goals:

- Clear water and Sanitation: wrong battery management can pollute water.
- Affordable and Clean Energy: batteries are part of the strategy in many countries to accumulate energy and provide it at a cheaper price.
- Industry, Innovation, and Infrastructure: battery industry and recycling technologies must develop to be more sustainable.
- Responsible Consumption and Production: battery production causes impacts in the environment, so it is important to improve this process using recycled materials.

1.2. Research questions

The present study has the goal to better understand the extended producer responsibility and regulations involving LIB end-of-life management among Germany, France, and Spain. To support this target, some research questions were made to define the directions of this work:

- What are the requirements of EPR regarding lithium batteries in France, Germany, and Spain?
- What are the legal requirements of logistics, considering transboundary operations, regarding lithium batteries in France, Germany, and Spain?
- What are the legal requirements of treatment, considering recycling and refurbishment, regarding lithium batteries in France, Germany, and Spain?
- What are possible extra requirements regarding lithium batteries in France, Germany, and Spain?

1.3. Scope of the study

The present study has the goal to better understand the current situation of LIB end-of-life management regarding obligations of EPR in the three countries related to the current job of the author: Germany, France, and Spain.

To facilitate this process, a literature review presents the LIB history, current situation, forecast for the next years, also a review of end-of-life LIB management, and a further analysis of EPR approaches.

The materials research design will initially explain the methodology of data collection and after the regulations will be discussed. Since this study is a review of obligations, firstly a review of EU regulations, that cover the three countries, will be presented and, after, country level regulations. For a better understanding on how regulations are applied, some illustrative case studies will be discussed.

2. Literature Review

The literature review of this thesis has the goal of presenting an overview of lithium battery history, the current situation of these batteries in Europe, how the end-of-life items are managed, and the responsibility of the producers with the end-of-life LIBs. The presentation of these topics is important to support the need to understand the current regulations regarding LIB management for producers, the possible future changes and how the countries of the thesis are working together.

2.1. Lithium batteries history

Lithium was discovered in 1817 by Arfwedson and Berzelius and it was isolated through the electrolysis of lithium oxide by Brande and Davy in 1821. However, By the end of the sixties and early seventies the first primary lithium batteries started to be commercialized in the market. A primary battery is a portable voltaic cell that was not rechargeable. At this moment, many different cathodes started to be considered for the lithium batteries, such as: sulfur dioxide, polycarbon monofluoride, manganese oxide, copper oxide and polyvinyl pyridine. (Reddy et al., 2020)

During the commercialization of primary LIB, research began to be conducted focusing on secondary lithium batteries. A secondary battery is a portable voltaic cell that is rechargeable. In 1991 Sony Co., based on Lithium Cobalt Oxide (LCO), and one year after A&T Battery Co. (Asashi Kasei Co. and Toshiba), started to offer the first secondary LIB to the market, and finally a battery was simultaneously small, light, and durable (Li et al., 2018). In 2019 Akira Yoshino, John B. Goodenough, and M. Stanley Whittingham received the Nobel Prize of Chemistry *"for the development of lithium-ion batteries"*.

By the end of the 90s the first EVs were introduced in the market however their performance was slow (about 75 mph) and high pricing compared to non-EVs. According to the manufacturer Nissan, Altra was the first EV to use LIB, had maximum estimated range of 120 miles (city) on a five-hour 200V paddle induction charge. (Nissan Motor Corporation, 2022)

The Lithium Manganese Oxide (LMO) batteries were a second generation of rechargeable lithium batteries that started to be present in the market during the beginning of 21st century. Another class of cathode that started to be used was the $LiFePO_4$ that supported the creation of the LFP batteries. And the third group of cathodes, and most fruitful for EVs, is the Ni-Based that brought the Ni–Mn–Co oxide (NMC) and Ni–Co–Al (NCA) oxides (Li et al., 2018).

Moreover, in 2002, the first laminated LIB was developed to making them ideal for small and portable devices as laptops, cameras, and mobile phones.

Since the last decade (Figure 4), the LIB started to dominate the market of wireless electronic devices due to the high energy density, low weight, and fast charging process. And because of it, EV industry kept considering this type of battery a satisfactory solution for e-mobility.

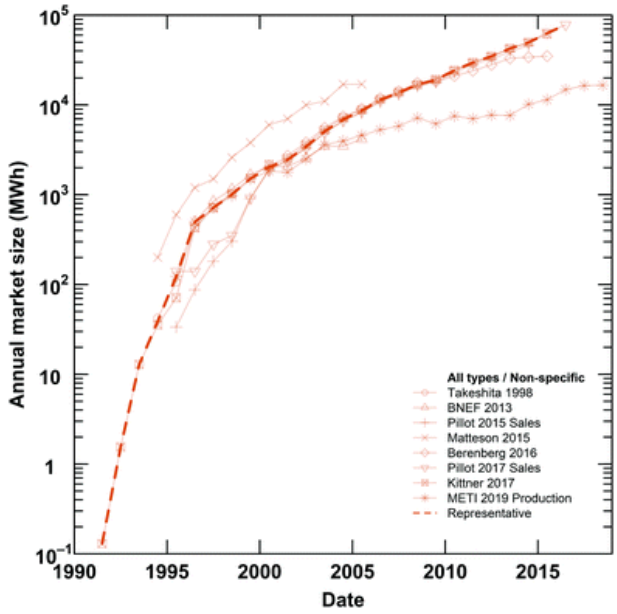

Figure 4 *Lithium-ion market size measured in cell energy capacity. (Ziegler & Trancik, 2021)*

Another key point is the decrease of prices that LIB had during the last two decades due to the improvement of technologies (Figure 5).

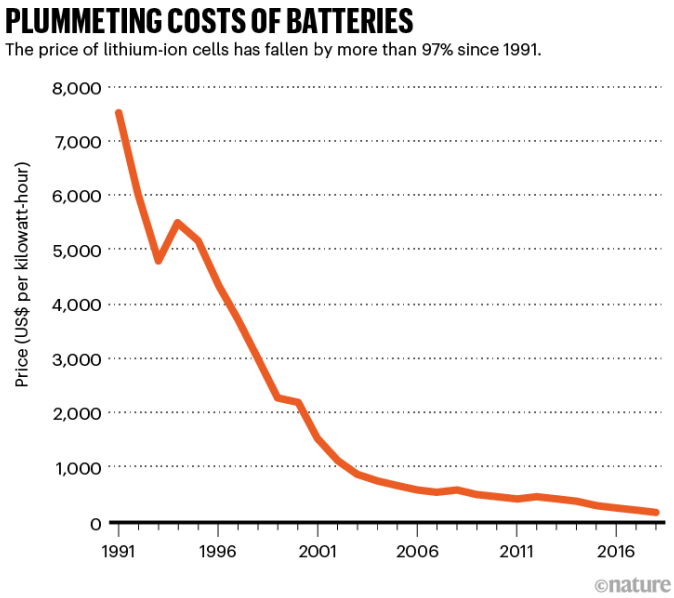

Figure 5 *Plummeting costs of lithium cells. (Castelvecchi, 2021) apud (Ziegler & Trancik, 2021)*

2.2. Lithium batteries current situation and forecast

Based on Bloomberg New Energy Finance (Figure 6), a strategic research provider covering global commodity markets, only for EVs by the end of 2030 the annual market size will be 6800% bigger than in 2015 around the world. The regions with more potential of increasing are China, United States and Europe (Curry, 2017).

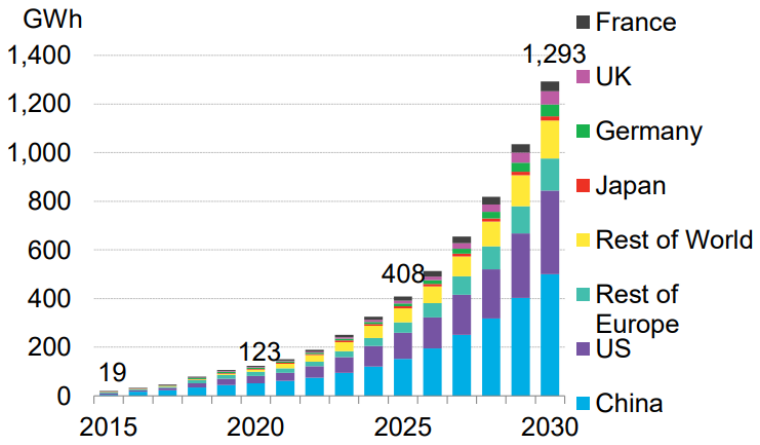

Figure 6 *Forecasted demand for lithium-ion batteries from EVs, 2015-30 (GWh)* (Curry, 2017)

Regarding the four main types of LIB, the material composition changes between each other because of the different cathodes and technologies. (Table 1)

Table 1 *The chemical composition of individual lithium-ion batteries.* (Winslow et al., 2018)

Material	LCO (mass%)	LFP (mass%)	LMO (mass%)	NMC (mass%)
Aluminum	5.2	6.5	21.7	22.72
Cobalt	17.3	0.0	0.0	8.45
Copper	7.3	8.2	13.5	16.6
Iron/Steel	16.5	43.2	0.1	8.79
Lithium	2.0	1.2	1.4	1.28
Manganese	0.0	0.0	10.7	5.86
Nickel	1.2	0.0	0.0	14.84
Binder	2.4	0.9	3.7	1.39
Carbon(non-graphite)	6.0	2.3	2.3	3.47
Electrolyte+Solvent	14.0	14.9	11.8	1.66
Fluoride	0.0	0.0	0.0	4.99
Graphite	23.1	13.0	16.3	0.0
ThermalInsulation	0.0	0.0	1.2	0.0
Oxygen	0.0	0.0	12.4	4.52
Phosphorus	0.0	5.4	0	2.04
Plastics	4.8	4.4	4.5	3.29

In Europe, according to the Battery Atlas 2022 (Heimes, 2022), in 2030 the rate of LIB production capacity will be fifty times bigger than in 2020. Passing from 25 GWh to around 1300 GWh. Half of it will be covered by European players (725 GWh), followed by Asian (360 GWh), and USA (200 GWh).

According to Kushnir & Sandén (2012), the energy density of LIB is around 160 g of lithium per kWh. So, based on the demand forecast presented for Europe, around 116,000 tons of lithium will be needed in the year of 2030 to produce all the LIB.

Considering these forecasts, a critical point is to understand the source of raw materials to produce lithium batteries cells. Based on the report A Vision for a Sustainable Battery Value Chain in 2030 (World Economic Forum, 2019), the main suppliers are in South America, Africa, and Asia (Figure 7). So, logistics challenges of raw material are already in the radar of producers and consumers.

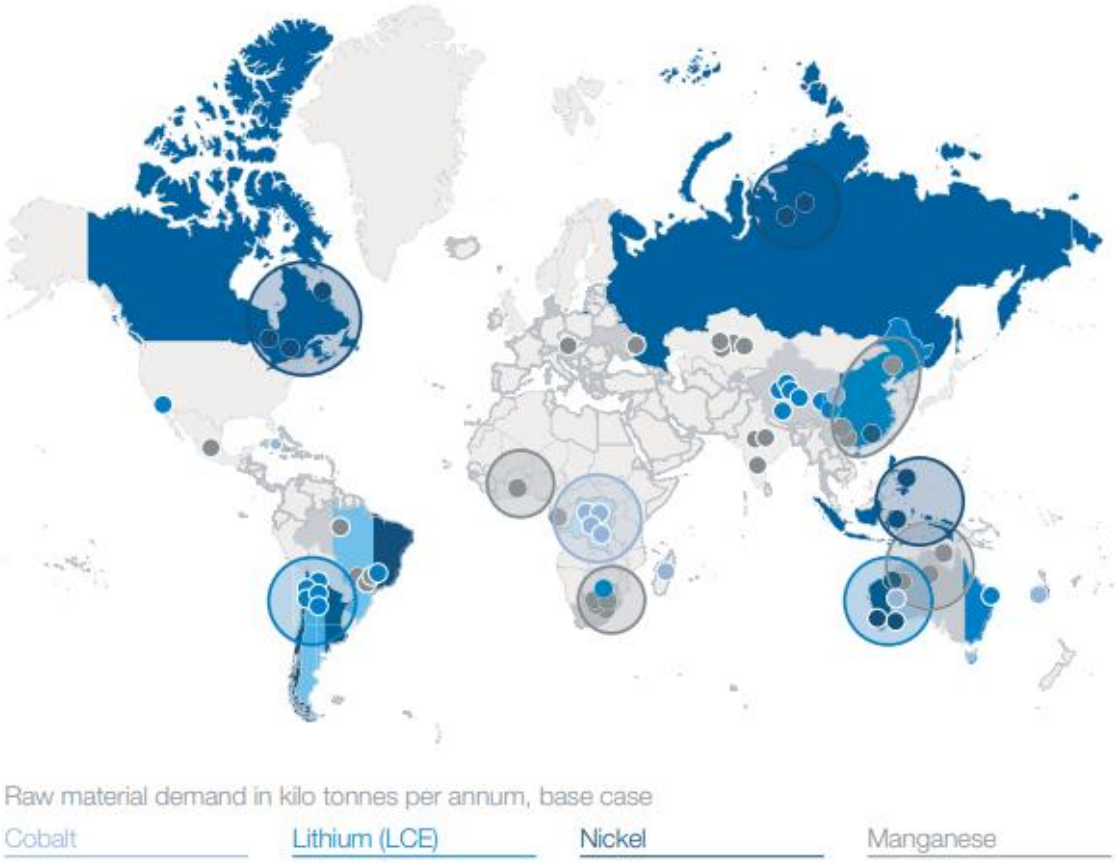

Figure 7 *Major mining locations for cobalt, lithium, nickel, and manganese.* (World Economic Forum, 2019)

Furthermore, as presented in the Figure 8, the mining process consumes a huge volume of water and most part of the sites are in high water stress areas (International Energy Agency, 2022).

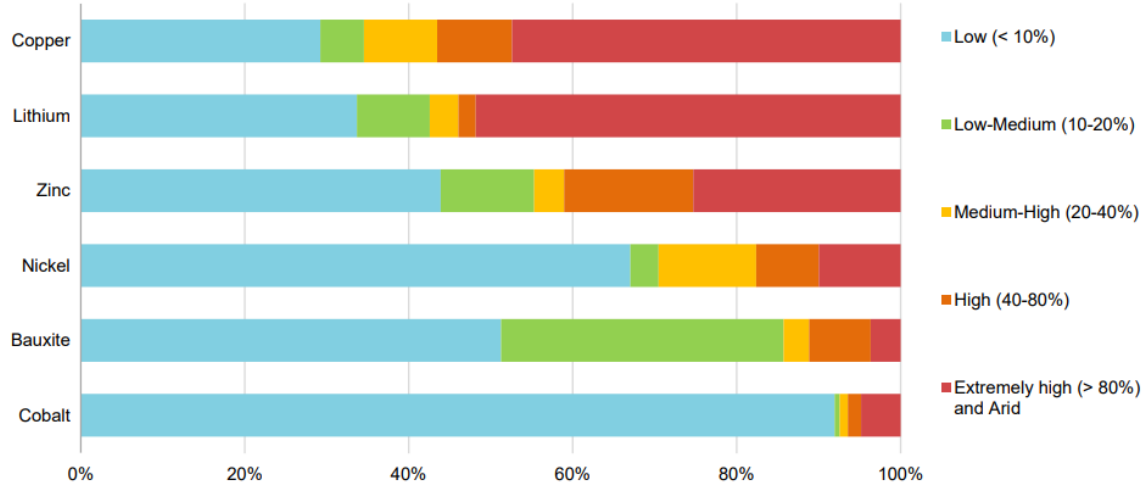

Figure 8 *Share of production volume by water stress level for selected minerals*. (International Energy Agency, 2022)

This is a crucial point of the discussion related to the necessity to create a closed loop process for lithium batteries, and part of it is the designation of an extended producer responsibility from the raw material extraction to the end-of-life of its products.

2.3. Lithium batteries end-of-life management

Lithium batteries are considered a dangerous waste due to their characteristics of chemical hazard, interaction hazard, thermal runaway, and fire hazard (Diekmann et al., 2018).

Since LIB are dangerous, the end-of-life management of this item is a matter of many studies. Moreover, since LIB use minerals that are scarce, the reuse or recycling of these materials is an environmental, economic, and social interest of society. Currently, the management of LIB can be divided by three categories: reuse, refurbishment, and recycling.

The reuse of batteries is a process that is being increasing due to the first batch of items getting old and losing its performance. For example, according to Pagliaro & Meneguzzo (2019), part of the energy storage system installed at Amsterdam's Arena is comprised 250 second-life batteries originating from EV 24 kWh battery packs. The reuse is the best solution for LIB due to the reduced consume of energy and materials. However, since batteries have different specifications and are not standard, it is hard to fit batteries in different markets as present by case before.

The second solution for end-of-life LIB is the refurbishment. Batteries usually constitutes many cells configured in series or parallel. Since the battery is not presenting a satisfactory performance, instead of directly recycling it, there is the possibility to assess the quality of each cell and keep the ones that are still good and replace the low performance cells for new ones.

According to NOWOS (2022), a young European start up related to end-of-life LIB management, the refurbishment process is based in two steps: diagnostic to understand the conditions, repairability and costs; repair service that is based on repairing the battery’s cells and replace the defective cells. However, refurbishment is a process that has a high cost of human resources due to the workload and necessary expertise.

Recycling is still the biggest solutions for LIB due to the economics and possibility to escalate. Nowadays, there are four technologies considered for recycling LIB: hydrometallurgy, pyrometallurgy, direct recycling, and combined pyrometallurgy and hydrometallurgy.

According to Baum et al. (2022), the direct method is where the cathode material is removed for reuse or reconditioning, and it is necessary disassemble the batteries to sort useful materials. This process is interesting because can be used for any kind of LIB, however due to the manual work of removing the cathode material it is not scalable yet (Figure 9).

Pyrometallurgy uses heating to convert metal oxides used in battery materials to metal compounds. This method is used because it allows flexibility in battery feedstock and possibility to process vast number of batteries. (Baum et al., 2022)

Hydrometallurgy process uses aqueous solutions and after precipitated using pH variations or solvents for extracting and separating cathode metals and run with temperatures below 100 ◦C (Baum et al., 2022: Jung et al., 2021) (Baum et al., 2022: Jung et al., 2021) . This technology is practiced in China, and it is interesting because consumes less energy and requires lower capital. (Jung et al., 2021)

The use of pyrometallurgy and hydrometallurgy combined is the current trend topic for LIB recycling due to the effectiveness of each technology in different steps of the process. According to Baum et al. (2022), publications related to this mixed technology represents around 65% of the total number of publications of LIB recycling technologies.

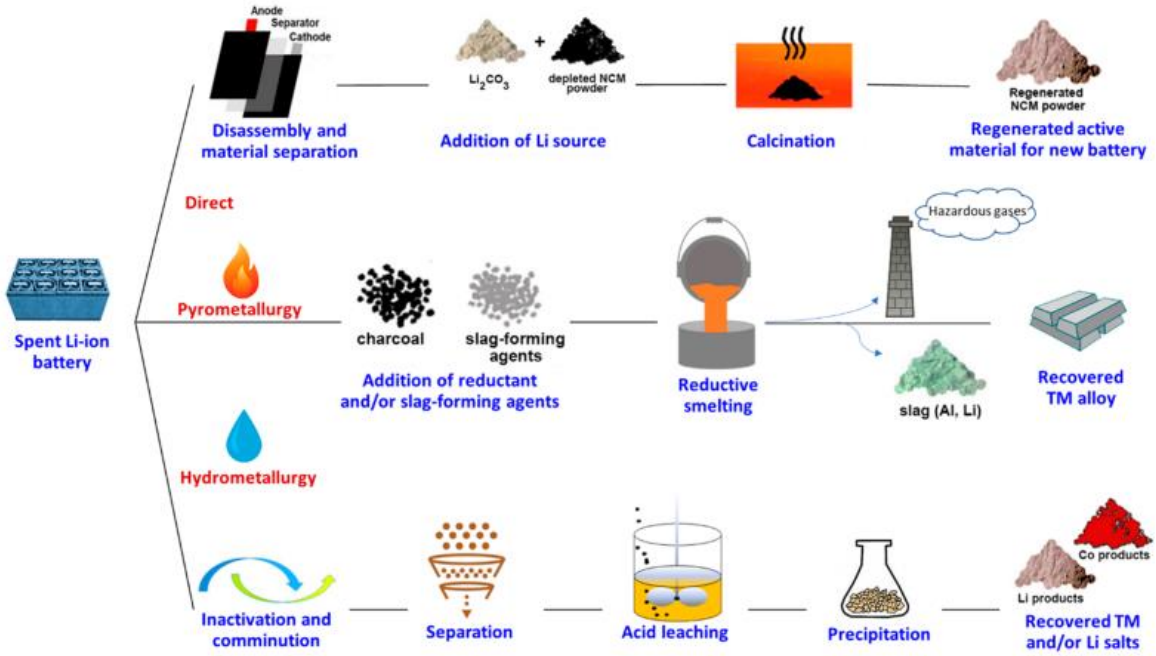

Figure 9 *The main recycling methods for recovery of Li-ion battery active* materials. (Baum et al., 2022)

As presented in the Figure 9, it is possible to see that the direct recycling process is a non-destructive process that is more environmentally friendly. However, it is hard to do this process simultaneously for different cathodes. The other two processes presents higher recycling rates. But the pyrometallurgy may needs more processes to recover materials effectively, and hydrometallurgy is a complex process that uses toxic reagents and has a high cost. (Costa et al., 2021)

The recycling rates of minerals in LIB is still low and European Commission set some targets for 2030 (Table 2).

Table 2 *Recycling ratios of LIB.* (European Commission, 2020)

Indicator	**2020**	**2030**
Portable battery takeback	45%	65%
EVs and industrial battery takeback	100%	100%
Overall Recycling efficiency	50%	60%
Recycling efficiency for Cobalt	90%	95%
Recycling efficiency for Copper	90%	95%

Recycling efficiency for Lithium	35%	70%
Recycling efficiency for Nickel	90%	95%

Current research already present recycling efficiencies of cobalt, nickel, manganese and lithium of more than 95% via leaching solutions processes. To separate metals of these complex solutions, purifications processes are proposed, and the current efficiencies rates for cobalt and nickel are more than 90%, and 80% for lithium. However, it is important to understand that these efficiencies are only in research level, the current recover of lithium in the recycling industry of LIB much lower. (Tian et al., 2022)

According to Battery Atlas (Heimes, 2022), the current main concentration of LIB recycling facilities is in Germany, followed by Nordic countries and Netherlands (Figure 10). This is expected because these countries are also the more developed of the energy transition of EV that promises generated vast amounts of LIB waste.

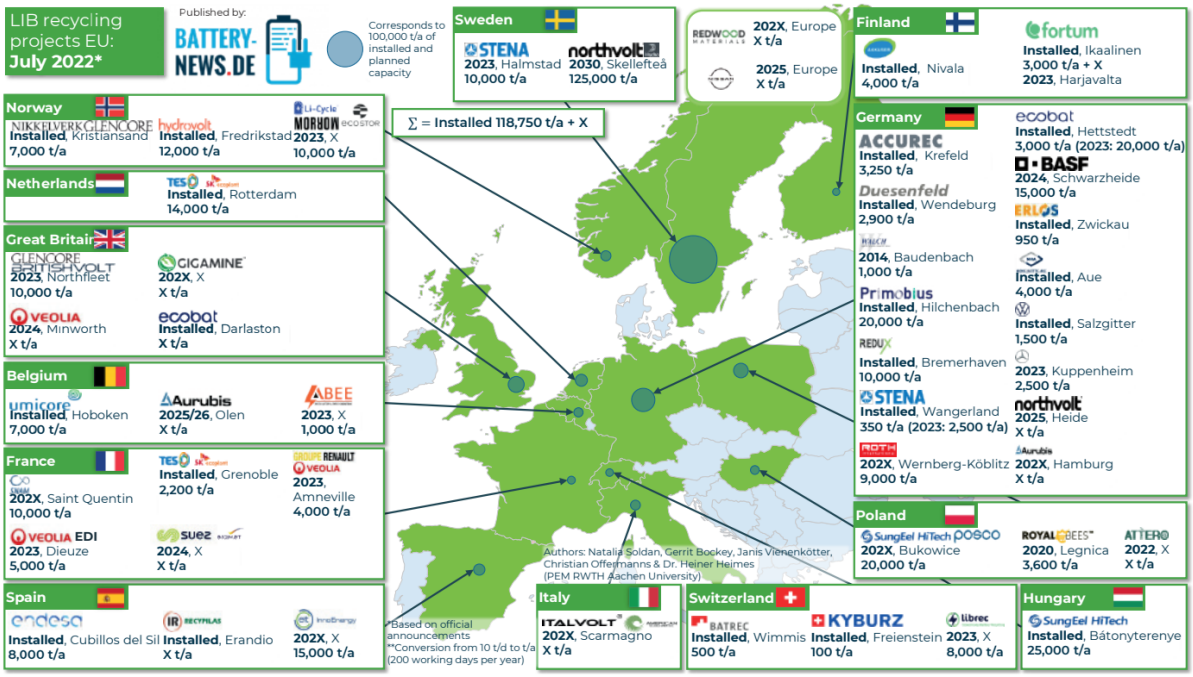

***Figure 10**- Lithium-ion recycling facilities in Europe* (Heimes, 2022)

2.4. Lithium batteries recycling facilities projection

Based on the information presented of the need of lithium in Europe in 2030, the average ratio of lithium in a battery, and the amount of recycling facilities projected for 2030, it is possible to estimate how much more tons recycling facilities need to be able to close the loop, considering no new extraction of raw lithium.

The total demand of lithium for 2030 was projected by this study as 116,000 tons and the current ratio of this metal in LIB is around 1,5% of mass, so around 7,750,000 tons of batteries will be produced in the last year of this decade. The total potential of recycling facilities presented by the Battery Atlas (Heimes, 2022) for 2030 is of around 400,000 tons for LIB, so this capacity would be able to recover only around 5% of the total demand of lithium of the European market.

2.5. Review of extended producer responsibility systems

Since LIB was introduced in the market, producers have had the responsibility to manage these items, that are considered dangerous, during their use and disposal. Recently discussions regarding the promotion of circular economy of these items are increasing to make this business more sustainable.

In the EU, for example, there are no regulations governing LIB recycling, but a draft regulation. That is a repealing of the Directive 2006/66/EC of 2006. (Bird et al., 2022) However, another directive created in 2009, the 2009/603/EC (European Union, 2009), and repealing the Directive 2006/66/EC (European Union, 2006), is focused on the requirements for registration of producers of batteries and accumulators to better control batteries put in the market. Based on it, the EPR in Europe became clearer in the market and systems could be started.

EPR is based on the polluter-pays principle (PPP) that emphasizes internalization of the externalities related to the end-of-life products (Gupt & Sahay, 2015), and to promote the design of products with lower environmental impacts at end-of-life (Mayers, 2008). Most part of EPR systems are mandatory for producersand the use of voluntary schemes is still limited (OECD, 2016).

For established markets, with clear legislation, EPR systems are already in place for a long time with enough benchmarking for discussions and reviews. In Europe, the first producer responsibility organization (PRO) was founded in the late 1990s and in 2007 there were already 250 different organizations (Mayers, 2008).

The EPR can vary between countries depending on its regulations and authorities' structures. The mandated product takes back obligations and economics instruments may change. (Table 3)

Table 3 *Take back obligations and economic instruments of EPR systems (Gupt & Sahay, 2015)*

Take Back Obligations	Product take back mandate and recycling rate targets	Manufacturers and retailers have the obligation to take back EOL products and set recycling rates. Usually made via PROs.
	Voluntary products take back mandate and recycling rate targets	Require voluntary take back withoutpenalties.
	Mandatory take back and targets with a tradable recycling scheme	The same obligations of the mandate take back with the possibility to trade credits of recycling among producers.
Economic Instruments	Advanced recycling fee (ARF)	Consider in the pricing of the product to cover cost of managing EOL products.
	Recycling fee combined with recycling subsidy	Use of ARF revenue or post-consumption recycling fee to subsidy the manufacturers and raw materials extractors for getting waste recycled.
	Deposit refund system (DRS)	Combination of tax on the product and rebate or refund of when the EOL item is returned by users. It encourages the reuse or recycling of materials.
	Material taxes	Taxes based on material's dangerousness. Encourages producers to uses less harmful material.

In Europe, many countries have institutions for the supervision and tax management of the electrical and electronics equipment (EEE) producers (Figure 11). These PRO institutions are usually called Compliance Scheme (CS). (Mayers, 2008)

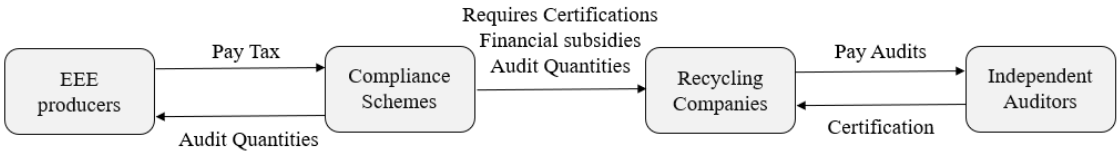

Figure 11 *EPR system based in Compliance Schemes for waste management*

The PROs are usually established by a pool of companies that has the same type of products, producers, or waste collection and recycling services. Corepile and Screlec, in France, are examples of a pool of companies working with batteries and accumulators (Table 4). The service of PROs involves the pickup of end-of-life products from householders or collection points, transporting, treatment, recycling, product labelling and, finally, reporting to the government (Mayers, 2008).

The role of the PROs is to be a facilitator among the stakeholders of the end-of-life product management, guaranteeing the quality of the service and right destination of waste. Because of it, producers and recycling companies have the interest to register in PROs due to better prices and standardization of waste.

Table 4 *Example of battery compliance scheme in different countries of Europe*

Country	**Compliance Scheme**
Belgium	Bebat
France	Corepile
France	Screlec
Germany	GRS Batterien
Many Countries	European Recycling Platform
Netherlands	Stibat
Poland	Reba
Portugal	Ecopilhas
Spain	Ecopilas
Sweden	El-Kretsen
United Kingdom	Batteryback
United Kingdom	Valpak

China has an interesting case of an initial different approach to promote EPR responsibility of electrical and electronics equipment (EEE) before adhering the CS method. Initially the EPR system for e-waste started to be prepared in 2009 with a program of subsidy for consumers selling their old electronic devices to buy a new one, however, even with an incredible recycling ratio of 84,5%, the format of the system was changed due to its costs (Cao et al., 2016).

In 2012, following Europe and Japan, China decided to promote the EPR system based on tax administration, subsidy, legal liability, supervision, and supplemental rules (Government of China, 2012).

3. Research design and data collection methodology

This research is designed to review the regulations of producers regarding the management of end-of-life LIB in different layers: supranational (European Union) and national.

Considering that some past studies approached this topic, part of this review was presented in the literature review. However, since regulations are changing, this research brings recent published enforcements for products containing LIB.

To have a clear view of the information gathered from each country considered on this research, the use of multiple tables was defined as a most visual way to present the obligations of each stakeholder in each country. Hypothetical case studies based in real cases faced by the author in the market will be also presented to understand how the regulations are applied for batteries producers and distributor in Spain, France, and Germany, in a practical way.

Even based in regulations, to bring a practical point of view for subject, corporative and institutional reports were considered during the research, and specialists of Europe were interviewed to expose their challenges when operating LIB end of life management. The interviewed specialists are involved in different ways with this topic, as: compliance consulting, recyclers, take back program managers, compliance scheme, and waste carriers.

4. Results

During the research process of the regulation in EU level and country levels, it was possible to understand that many approaches of the national regulations still follow the EU directives for batteries and accumulators. Moreover, most part of the regulations are about any kind of batteries, not only lithium-ion. Because of it, an initial topic presenting the EU regulations will be presented, and, after, a topic comparing the national regulations of Germany, France, and Spain.

4.1. EU Regulation

Currently, the EU does not have regulations governing LIB recycling, but a draft is under review by the commission. Its document is the repealing of the Directive 2006/66/EC (European Union, 2006) of 2006. (Bird et al., 2022) that provides directives of the batteries and accumulators and waste batteries and accumulators and is a repeal of the Directive 91/157/EEC (European Union, 1991) created in 1991 that has the initial directives on batteries and accumulators containing certain dangerous substances.

However, the commission decision created in 2009, the 2009/603/EC (European Union, 2009), in accordance with Directive 2006/66/EC (European Union, 2006), and is focused on the requirements for registration of producers of batteries and accumulators to better control batteries put in the market.

4.1.1. Directive 2006/66/EC

The current for batteries and accumulators for European Countries is the 2006/66/EC (European Union, 2006). It was created based on Decision No 1600/2002/EC (European Union, 2002) and Directive 2002/96/EC (European Union, 2002). The directive of 2006 establishes rules regarding the placing on the market of batteries, and specific rules for the collection, treatment, recycling, and disposal.

The main changes of this directive are the definition of portable battery and automotive battery, which has relationship of the LIB becoming more popular in the market, review of

forbidden dangerous types of batteries composition to be produced, and collection schemes via accessible collection point or distributors take back services without charges.

Regarding collection targets, since 2016 all member states should collect: 45 %. However, the recycling target for batteries different from lead-acid or nickel-cadmium is 50%. (European Union, 2006)

This regulation also introduced the differentiation of the economic operators of LIB between producer, distributor, recycler, and collector. Producers, or third parties acting on their behalf, finance any net costs of collection, treatment, and recycling of batteries. Producers must also be registered. (European Union, 2006)

About end-of-life LIB, Member States shall prohibit the disposal in landfills or by incineration of waste industrial and automotive batteries, and the treatment and recycling may be undertaken outside the Member State concerned or outside the Community respecting the regulation 259/93 (European Union, 1993). Batteries can be treated in different countries of origin based on regulations 259/93 (European Union, 1993), 1420/1999 (European Union, 1999), and 1547/1999 (European Union, 1999). Regulation 1547/1999, regarding control procedures to shipment does not mention lithium.(European Union, 1999) .

4.1.2. Commission Decision 2009/603/EC

The commission decision 2009/603/EC (European Union, 2009) established requirements for registration of producers of batteries and accumulators in accordance with Directive 2006/66/EC (European Union, 2006). After three years of the directive, the Council decided it was appropriate to specify the information which producers of batteries should provide when they apply for registration.

The registration of producers is done via national authorities or national producer responsibility organization. For the registration process, producers must provide the type of batteries placed on the market and how they meet the EPR (individual or compliance scheme). Registration fees may be applied by registration bodies considering cost-based and proportionality.(European Union, 2009)

4.1.3. New regulatory framework for batteries - 2020/0353

Since 2006, no significant changes have been made by the European Commission regarding use and management of batteries and accumulators. In December of 2020, the proposal of a new framework was presented, and it is in process of validation of the Council for approval (Figure 12).

The current framework is focused on end-of-lime management of batteries, so it does not cover the full lifecycle of this product. The proposal for a new framework has the goal of improving the sustainability and competition of EU battery value chains, from the design to disposal (Halleu, 2022).

To cover the full lifecycle of the product, the new framework brings propositions regarding carbon footprint rules, minimum recycled content, performance, and durability and safety criteria. In that case, lithium is already mentioned and the goals for this material would be:

- Recycling Efficiencies
    - 2025: 65 % of average weight of lithium-based batteries.
    - 2030: recycling of 70 % by average weight of lithium-based batteries.
- Levels of recovered materials
    - 2026: 35% lithium.
    - 2030: 70% lithium.

Interesting topics are approached by the commission regarding responsibility and design. Due diligence requirements are proposed to guarantee the whole lifecycle of batteries, from the raw material extraction to the end-of-life management is respecting the human rights, social rights, human health, and the environment. Regarding design, it is proposed to create harmonized standards for a common charger and readily and safely remove procedures of batteries from the products.

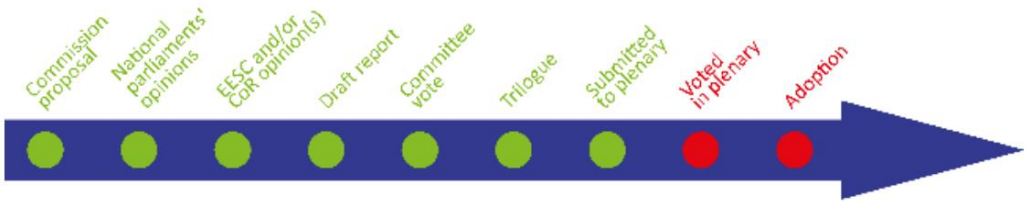

Figure 12 *Past and current stage of the new framework for batteries to be implemented.*(Halleu, 2022)

Regarding the carbon footprint, there are two propositions being considered in the framework for industrial (more than 5 kg) and EV batteries. The less ambitious is to define mandatory the carbon footprint declaration via Product Environmental Footprint Category Rules, and the more ambitious proposition is to present carbon footprint performance thresholds for batteries as a requirement for placement on the market. Declarations would also demandthird-party verification via notified bodies (Halleu, 2022).

For end-of-life battery management, the new framework proposes the reuse and repurposing of industrial batteries. The less ambitious proposition is to consider repurposing as a waste treatment and that second life batteries must respect the same qualities of a new one. The more ambitious proposition is that second life is mandatory (Halleu, 2022).

4.1.4. Regulation No 1013/2006/EC

Regarding waste logistics, the Regulation (EC) No 1013/2006 (European Union, 2006) is the base of it, and nowadays there is an amendment, Commission regulation No 255/2013 (European Union, 2013), named Green List that includes several types of waste that can be transported using a same form presented in the Annex VII. For transboundary movements inside EU, it is necessary to also have a notification form (Annex IA) and a document (Annex IIA) declaring the type of waste and quantities. In these documents, it is necessary to include the waste code, that for LIB are: A1180/ B1110 that are related to waste electrical and electronic assemblies or scrap containing components such as accumulators and other batteries, and code 16 06 05 that is related to other batteries and accumulators, different of lead, Ni-Cd, mercury, or alkaline batteries.

The competent authorities may also request extra documents, as chemical analysis of the composition of the waste, description of the treatment process of the facility which receives the waste, etc.

4.2. National Regulation

Regarding the three chosen countries, Spain is a more specific country because it has 17 autonomous communities that can have specific regulations. For the present study, only national regulations were considered.

As batteries and accumulators are a unique type of material and a dangerous goods, each country has specific regulations for it. In France, the regulations regarding batteries are covered by the Code de l'environnement (Code de l'Environnement, 2022), from articles 541 to 543. In Germany, there is the BattG (Batteries Act, 2009), first version presented in 2001, that regulates these items in the country. In Spain, most part of the regulation are on Real Decreto 106 (Real Decreto 106/2008, 2008) that was initially presented in 2008.

4.2.1. Definitions

The initial information needed to understand the regulations, is the comprehension of the definitions that each country gives to some important terms and actors related to battery management. The three main points that have differences are obligated parties, placing on market, and distributor (Table 5).

Table 5 *Battery management terms definition.*

Definitions	France	Germany	Spain
Obligated parties	Environmental Code Art. L541-10-1	The Batteries Act 2009	Royal Decree 106/2008
	Any natural or legal person who develops, manufactures, handles, treats, sells or imports waste-generating products or elements and materials used in their manufacture. Producer means any person located on the national territory that, irrespective of the selling technique used, including by remote communication, places batteries or accumulators on the market.	Manufacturer means anyone who, regardless of the sales method, commercially puts batteries on the market.	Any natural or legal person who, irrespective of the sales method involved, places batteries and accumulators on the market for the first time, including those batteries and accumulators incorporated into appliances or vehicles, as part of his professional activity.

Placing on market	Environmental Code Art. R543-125-10	The Batteries Act 2009	Royal Decree 106/2008
	Placing on the market of the national territory means supplying or making available to a third party for the first time on the national territory by means of manufacture, introduction or importation of batteries and accumulators intended to be distributed or used by the final user on the national territory.	Placing on the market means the supply to third parties for payment or free of charge with the aim of distribution, consumption, or use.	The supply to a third party or the provision within the Spanish territory, upon payment or on a free-of-charge basis, of batteries or accumulators manufactured in Spain, purchased in countries within the European Union or imported from countries outside the European Union.
Distributor	Environmental Code Art. R543-125-8	The Batteries Act 2009	Royal Decree 106/2008
	Distributor is any person who, whatever the distribution technique used, including by remote communication, supplies batteries or accumulators on a commercial basis to the person who will use them.	Distributor means anyone who, regardless of the distribution method, offers batteries commercially for end users. 'Offering batteries' is the presentation or making available of batteries aimed at concluding a purchase contract; this also includes the request to submit an offer.	Any natural or legal person who supplies or sells batteries or accumulators to end-users within the scope of their professional activity.

4.2.1. Obligations

The obligations in each country are the main objective of the regulations and it has different approaches but always based on producer and distributor.

The first part identified as important related to EPR, is to understand in which case the producers or the retailers are responsible of the LIB (Table 6). B2B is a business-to-business market relationship and B2C is a business-to-consumer market relationship.

Table 6 *EPR definition for different business models*

Business model	France	Germany	Spain
	Environmental Code - Art. R543-125 7°	The Batteries Act 2009 - Paragraph 2.15	Royal Decree 106/2008 - Art. 3º
Case of sales to retailers or distributors	Producer	Producer or Retailer	Producer
Case of sales to B2C end-user	Producer	Producer	Producer
Case of sales to B2B end-user	Producer	Producer	Producer
Foreign entity with foreign VAT in case of sales to local retailers or distributors	Retailer	Producer or Retailer	Producer or Retailer
Foreign entity with foreign VAT in case of sales to local B2C end-user	Producer	Producer	Producer
Foreign entity with foreign VAT in case of sales to local B2B end-user	Producer	Producer	Producer

Foreign entity with local VAT in case of sales to local retailers or distributors	Retailer	Producer or Retailer	Producer or Retailer
Foreign entity with local VAT in case of sales to local B2C end-user	Producer	Producer	Producer
Foreign entity with local VAT in case of sales to local B2B end-user	Producer	Producer	Producer

Since the extended producer responsible is defined for each business model, it is necessary to understand the obligations is related to the responsibility of the distributor communicating with the customers, deposit and take back obligations (Table 7).

Table 7 *Distributor, deposit and take back obligations*

Obligations	France	Germany	Spain
Distributor Information to customer	Environmental Code	The Batteries Act 2009	Royal Decree 106/2008
	In stationary shop or on website for online-shop. Distributors inform users of the possibility of bringing waste portable batteries and accumulators to their points of sale. The containers made available to users for this purpose are highlighted and easily accessible.	In stationary shop or on website for online-shop. Distributor shall inform end-user that batteries can be returned free of charge after use at the point of sale and that the end user is legally obliged to return waste batterie	In stationary shop. As for distributors, they must also inform customers on the possibility of handing batteries, accumulators, and battery packs over upon use at the point of sale.
Deposit obligation	Environmental Code - Article R543-128-5	The Batteries Act 2009	Royal Decree 106/2008
	The return bonus aimed at preventing waste abandonment shall take the form of a financial amount paid to the holder of the waste or a deposit returned to the user of the product when it is taken back. Its amount shall be set by the producer at a level sufficient to encourage the holder to return the used product or the waste resulting from it.	Distributors supplying automotive batteries to end users shall be obliged to charge a deposit of €7.50 including VAT per automotive battery if the end user does not return a waste automotive battery at the time of purchase of a new automotive battery. The distributor who collected the deposit is obliged to refund the deposit upon return of a waste automotive battery.	Producers of batteries may individually fulfil the obligations arising from extended producer responsibility set out in Law 22/2011 by setting up their own deposit, return and refund system as an individual form of extended responsibility. In case of charging the end-user and it returns the item, the same amount of the deposit must be returned to the end-user.

Take-back obligation for distributor	Environmental Code	The Batteries Act 2009	Royal Decree 106/2008
	Distributors of portable batteries and accumulators take back free of charge and without the obligation to purchase new batteries or accumulators waste batteries and accumulators of the same type as the batteries and accumulators that they market, and which are brought by users.	Every distributor shall be obliged to take back waste batteries from the end user free of charge at or in the immediate vicinity of the retail outlet.	In the case of separate collection points located in distributors' establishments, in a way that distributors shall be obliged to accept the return of spent portable batteries and accumulators free of charge from holders or end-users, nor may they require holders or end-users to purchase or acquire new portable batteries or accumulators.

Considering current and future business models, marketplace obligations is only presented France via their Environmental Code (Code de l'Environnement, 2022), stating that a marketplace seller is obliged to provide for or contribute to the prevention and management of the waste that comes from it in accordance with the provisions of Articles L. 541-10 and L. 541-10-8.

Considering the financial and legal requirements, the three countries present diverse ways to manage it, and the possibility of having authorised representants to manage batteries. (Table 8).

Table 8 *Financial and legal obligations and authorised representative*

Obligations	France	Germany	Spain
Voluntary authorised representative	Environmental Code - Art. R541-174	The Batteries Act 2009	Law 7/2022 - Art. 40
	Any producer of products whether established in France or in another Member State of the European Union or a third country may designate a natural or legal person established in France as an agent responsible for ensuring compliance	Authorised representative means any natural or legal person or partnership established within the scope of this Act whom a manufacturer without an establishment within the scope of this Act has appointed to perform on his own behalf all the tasks necessary to fulfil the manufacturer's obligations	Producers of products who are established in another Member State or in third countries and who market products in Spain shall comply with the obligations of the producer of the product provided for in this Act. To this end, they may appoint a natural or legal person in Spanish territory as an authorised representative.

Financial obligations and guarantees	Environmental Code - Art. R543	The Batteries Act 2009	Royal Decree 106/2008	
	The producer or the holder, approved to fulfil the obligations incumbent on it as a producer, shall set up take-back systems enabling battery users in terms of the collection, and treatment. Order of 20 August 2015 Approval Procedure and Specifications for Individual Systems for the Waste Portable Batteries and Accumulators Sector.	Producers or their authorised representatives shall be obliged to take back free of charge waste batteries collected from distributors, as well as waste batteries collected by public waste management authorities and waste portable batteries collected by voluntary to treat and recycle.	All costs of operations for the collection and management of batteries including separate collection, transport, sorting, temporary storage, treatment, and recycling, shall be borne by producers or collective extended responsibility schemes or other entities acting on behalf of producers in accordance with the extended producer responsibility scheme used.	
Legal producer governance requirements	Environmental Code - Article L541	The Batteries Act 2009	Law 7/2022	Royal Decree 106/2008
	Producers fulfil their obligation by collectively setting up approved compliance schemes they provide governance for, transfer their obligation to, and pay a financial contribution for the fulfilment of their obligations. The compliance schemes and the individual systems are approved for a maximum duration of six years (the approval can be renewed).	Every manufacturer of portable batteries or their authorised representative must set up and operate their own take-back system for used portable batteries to meet their take-back obligations. The establishment and operation of the take-back system require the approval of the competent authority. Several manufacturers or their authorised representatives may cooperate in setting up and operating a compliance schemes.	Producers who opt for a compliance scheme for compliance with the obligations deriving from extended responsibility shall set up an association as provided for in Organic Law 1/2002, of 22 March.	Extended collective responsibility system organised by a group of producers of batteries together with other economic operators that may participate, to collectively comply with the obligations arising from extended producer responsibility in accordance with the provisions of Law 22/2011, of 28 July, and the Royal Decree. They shall constitute an association as provided for in Organic Law 1/2002, of 22 March.

Another key point approached by all the three countries is related to the targets of collection and recycling rates for batteries. Collection rates change per nation, but for all the countries the recycling rates follow the European Union targets (table 9).

Table 9 *Targets of collection and recycling rates*

Obligations	France	Germany	Spain
Collection Rates	Environmental Code - Art. R543-128-5	The Batteries Act 2009	Royal Decree 106/2008
	Producers of portable batteries and accumulators shall take measures to achieve an annual minimum national separate collection rate of 45%.	The take-back systems shall each achieve and permanently ensure a collection rate of at least 50% for waste portable batteries in their own system.	The minimum annual objectives at the state level must be met in each Autonomous Community. The following minimum rates of collection of waste batteries and portable accumulators must be achieved throughout the national territory: a) 25% from December 31, 2011. b) 45% from December 31, 2015. c) 50% from December 31, 2020
Recycling Rates	Order of 20 August 2015 based on European Regulation 2006/66/CE	Amendment to Law on Reorganization of Recycling Management and Waste of 2012 based on European Regulation 2006/66/CE	Royal Decree 106/2008 based on European Regulation 2006/66/CE
	Recycling processes shall achieve the following minimum recycling efficiencies the recycling of an average of 50% by weight of other batteries and accumulators, if not lead-acid or nickel-cadmium.	Recycling processes shall achieve the following minimum recycling efficiencies the recycling of an average of 50% by weight of other batteries and accumulators, if not lead-acid or nickel-cadmium.	Recycling processes shall achieve the following minimum recycling efficiencies the recycling of an average of 50% by weight of other batteries and accumulators, if not lead-acid or nickel-cadmium.

As discussed in the review of EPR schemes and possibilities to operate their responsibilities, for batteries there are different manners to manage it. All the three countries accept the LIB management via compliance schemes or collective systems, the option to manage LIB individually is not accepted in France, and in Spain it is possible to operate it via environmental fee to state (Table 10).

Table 10 *Compliance models for LIB management*

Compliance Models	France	Germany	Spain
	Environmental Code - Art. R541 and R543	The Batteries Act 2009 - Paragraph 7	Royal Decree 106/2008 - Art. 6º
Tax based	No	No	No
Environmental fee to state	No	No	Yes
Collective system	Yes	Yes	Yes
Compliance scheme	Yes	Yes	Yes
Individual solution	No	Yes	Yes

Regarding the registration of LIB management and put on market, in all the countries the producers must register their operations with the legal authorities. Moreover, in the three countries the operation reporting must be done annually.

4.2.2. Logistics

The main document for waste logistics is the Agreement concerning the International Carriage of Dangerous Goods by Road (ADR). This agreement was made via United Nations Economic Commission for Europe and all the countries of Europe, more some of Asia and Africa are members. China is not a member. It is specifically for dangerous good, so necessary for LIB. According to ADR, the sender is responsible for compliance with the packaging regulations and must prepare the material in accordance with the ADR regulations for lithium batteries. Batteries are to be transported under ADR SP 377 as dangerous goods und to be packed according to packaging instruction P909. The cargo securing of dangerous goods according to the ADR regulations must be checked before departure.

Another document used for goods transportation in UN is the *Convention relative au contrat de transport international de marchandises par route* (CMR), that is a waybill related to various legal issues concerning transportation of cargo by road. This document is used by any logistics services between two countries of UN.

For France, a part of the mentioned documents, for waste logistics and tracking it is necessary to register the waste responsible at TrackDechets platform and use the *Bordereau de suivi des déchets* (BSD) document. This is a form, that has similar goals of ADR, which aims to ensure the traceability of hazardous waste and to constitute proof of its elimination for the responsible producer.

For Germany and Spain, since the LIB waste management between countries is always made via recycling, a valorisation process, no extra documentation is needed apart the mentioned above.

Package labelling for battery transport is necessary in all these countries and are defined by the UN codes. The package must have a label sticked informing the type of waste (International Air Transport Association, 2021).

- UN 3091, Lithium metal batteries contained in equipment; or
- UN 3091, Lithium metal batteries packed with equipment; and
- UN 3481, Lithium-ion batteries contained in equipment; or
- UN 3481, Lithium-ion batteries packed with equipment.

For the current case, the right label would be the label UN 3481 (figure 13).

Figure 13 *UN 3481 label* (MySafeLabel, 2022)

Moreover, the batteries must also be packaged in the right way to avoid accidents. Usually, it is packed with a plastic bag or blister, and some material to absorb impact is put around.

Figure 14 *Lithium battery packaging example.* (International Air Transport Association, 2021)

4.3. Case studies

To have a better understand of how the regulations mentioned are applied, three business cases are proposed to analyse it: a distributor with B2C sales in Spain that recycles LIB batteries in France managing the batteries itself; foreign entity in Germany with local VAT in case of sales to local B2B end-user that sends the batteries to Spain for recycling managing the batteries itself; and a B2B distributor in France registered in a compliance scheme.

4.3.1. Local B2C distributor in Spain recycling LIB in France

The first case is a possible current real scenario due to the low capacity of Spain to recycle LIB. For this case, it will be considered a company that produces LIB for electric light vehicles, as scooters and bikes, in Barcelona for B2B and B2C markets. This company needs to understand its responsibility regarding the LIB end-of-life management and how to export these batteries to a recycling facility in France.

According to table 5, in Spain producers that are placing on market LIB in B2B and B2C market have the extended producer responsibility for this type of item. In that case, the company must register itself with legal authority's actor providing quantities of LIB put on market per year. Moreover, the producers must be sure that all the products have the right communication with the customer of the dangerousness, waste classification, and correct handling.

If the company of this case has physical stores, they must provide communication for the customer that they offer the service of take back. In case the sales are only online, this information must be provided in their website.

In Spain, there is no deposit fee obligation when selling the units, but this is something that the producer can apply for stimulating customer to take back the batteries correctly.

Since the take back is requested, the company must provide the service for free to the customers and the correct packaging for transportation. The company can be registered in a compliance scheme that could support the whole operation, but in this case, we will consider the company itself will manage it.

As presented in the topic of the regulations, the company must find a carrier with certifications for transporting waste and dangerous materials. For sending the batteries to France for recycling, the following documentation must be provided: Annex VII, Annex IA, Annex IIB of EU regulation 1013/2006, ADR and CMR. Since the origin is in Spain, the use of TrackDechet platform is not necessary and not possible, because the producer would need to have the SIRET number - s*ystème d'identification du répertoire des établissements*.

After the transportation of the waste to the recycling, the facility must provide to the company the total net weight of batteries recycled, date of reception for control and future reporting. The choice of the recycling facility is also an important moment, where operations certification and quality certifications, as ISO, must be validated to guarantee the right management of the waste and recycling rates.

4.3.2. Foreign entity distributing automotive batteries in Germany B2B that recycles the batteries to Spain

This second case considers a foreign entity in Germany that has a local VAT and operates with B2B market for automotive batteries. Due to the recycling costs in Germany, the company decides to send the batteries to Spain.

As presented in the first case, the initial task of the company is to validate their EPR upon the LIB. In that case, they also need to manage the end-of-life items, helping their customer to give the right destination of it. So, the company must register its operation with legal authorities reporting the volume of batteries put on market per year.

In Germany, companies can manage batteries via Collective system, Compliance scheme, and Individual solution. For this case we will choose the individual solution to compare with Spain. As we can see in the regulations presented, the process of the communication with customer, logistics and recycling process are the same.

An important point that differs the operation in that case, is that the distributor is obligated to charge the customer a deposit of €7.50 (including VAT) for each battery bought. Since the costumer take back this battery to the distributor, they must give the money back to the customer.

Another point in Germany is the take back obligations of distributors even for request of users that did not buy a new battery. In that case, the deposit fee is paid for whom initially sold the battery to the user, not the company that is doing the take back process. This company must only provide a take back certificate to the customer to ask the deposit fee back.

Since the logistic is also a transboundary operation, this distributor must use the same documents of the case before: Annex VII, Annex IA, Annex IIB of EU regulation 1013/2006, ADR and CMR.

4.3.3. Local entity distributing batteries for B2B market in France and registered in a compliance scheme

This case is the current situation of companies in France that distributes batteries. These companies must be registered in a compliance scheme or collective system to manage their end-of-life batteries.

In that position, must follow the same process of registering the company as a LIB distributor with the local authorities, the TrackDechet platform, and communicate with customer about their responsibility of managing end-of-life LIB.

Since the company is registered in a compliance scheme, each end-of-life item management must be done via compliance scheme. So, the company sends the request to the compliance scheme, and this entity will take care of the collection process, transport, and treatment. To create the request, it is important that the end user provides the conditions of the batteries to guarantee the right orientation for managing the items, e.g.: battery condition (non-damaged, damaged, critically damaged, leaking, etc.), quantities, weight per item.

In that case, the compliance scheme that defines the recycling destination and audit it. Compliance schemes have priority with recycling facilities because they have greater volume and, usually, better battery conditions for recycling. Also, in some cases, compliance schemes finance recycling facilities. So, most part of time compliance schemes manage batteries without transboundary operations.

After the process, the compliance scheme must provide the quantities to the distributor and this data will be used by annual reporting.

5. Conclusions

Understanding the EPR obligations of LIB ecosystem is an important to understand how to manage end-of-life items and how to achieve a sustainable relationship with a product that has a forecast to increase for many years in the market. For now, Europe is part of the main markets for portable batteries together with USA and China, and this continent is developing its policies regarding raw materials and waste management towards a circular economy.

As we could see, political alliances as EU and UN facilitates the process of countries to have more synergy when managing dangerous goods and defining their regulations. This is a crucial important step to simplify the operation of take back responsible and standardize the process among the countries presented in the study. However, each country still has some specifications that should be taken in account when working with batteries.

The complexity of LIB waste management, and the current regulations, stimulate that companies work with compliance scheme due to the expertise to operate, collect, treat, audit and report LIB put on the market.

Considering a new regulatory framework for batteries is under process of approval for the EU, the management and EPR of LIB should be more exigent and aligned with the SDG defined by UN. Consequently, all the nations should review their regulations to be convergent with this new framework that emphasis the carbon footprint and refurbishment as part of the life cycle of LIB. Moreover, LIB end-of-life responsible will need to increase their take back ratio and the recycling facilities must invest in research for improving their recycling ratios of precious raw materials, especially lithium.

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