EUROPEAN
COMMISSION

Brussels, 22.11.2018
SWD(2018) 245/2 final

This document corrects document SWD(2018) 245 final of 17.05.2018

Corrected are relevant policies (p. 37) and permitting requirements and authorities (p.43).

The text shall read as follows:

COMMISSION STAFF WORKING DOCUMENT

Report on Raw Materials for Battery Applications

Table of Contents

1. EXECUTIVE SUMMARY

The purpose of this document is to launch an informed discussion with the Member States and other stakeholders and to inform about the implementation of the Battery Action Plan, in particular the strategic action area “Securing the supply of raw materials”[1]. The document provides a snapshot on where the EU stands on battery raw materials. It highlights the challenges and bottlenecks of securing the supply of battery raw materials but, more importantly, it identifies large gaps in our knowledge at EU level.

Batteries are a key enabling technology for low emission mobility and for energy storage. Recent forecasts indicate that the demand for batteries both in the EU and globally will grow exponentially in the next years[2].

The challenge of creating a competitive and sustainable battery manufacturing industry in Europe is immense, and to catch up with the fierce competition (mainly from Asia) Europe has to strengthen all steps of battery value-chain, starting from the first one – ensuring a secure and sustainable supply of battery raw materials to the battery manufacturing industry.

The EU, thanks to the EU raw materials strategy[3] and the launch of the European Innovation Partnership on Raw Materials back in 2012, has all the necessary means to address the challenges by resorting to the following three pilars: (1) sustainable sourcing of raw materials from global markets, (2) sustainable domestic raw materials production, and (3) resource efficiency and supply of secondary raw materials.

The report focuses on four essential raw materials for batteries production namely: cobalt, lithium, graphite, and nickel. Other important raw materials for battery applications such as manganese, aluminium, copper, tin, silicon, magnesium, germanium, indium, antimony and rare earth elements (REEs) are briefly mentioned but they would require a more in depth analysis as outlined in the relevant paragraph on Alternative Materials. REEs are also materials of relevance to electromobility, in particular for electric traction motors. Some of these materials have a high economic importance while at the same time have a high supply-risk. Among the materials used in Li-ion cells, three are listed as critical raw materials (CRMs)[4] by the European Commission namely, cobalt, natural graphite and silicon (metal). Lithium is not a CRM, but has an increasing relevancy for the Li-ion battery industry.

The supply chain of these materials is potentially vulnerable to disruption. In view of the large quantities needed in the future, the sustained extraction and exploitation of these resources is fundamental and recycling of materials will increasingly become important for reducing the EU's dependency on third country markets and should be encouraged in the framework of the transition to a circular economy.

The report addresses more specifically the following key action of the Action Plan: *“Build on the EU list of Critical Raw Materials, established in 2017, to map the current and future primary raw materials availability for batteries; assess the potential within the EU for sourcing battery raw materials including Cobalt (Finland, France, Sweden, and Slovakia), Lithium (Austria, the Czech Republic, Finland, Ireland, Portugal, Spain, and Sweden), Natural Graphite (Austria, Czech Republic,*

---

[1] Strategic Action Plan on Batteries: COM(2018) 293 final

[2] Source: EIT Inno-energy http://www.innoenergy.com/

[3] The Raw Materials Initiative: COM(2008) 0699 final

[4] The 2017 list of Critical Raw Materials for the EU: COM(2017) 490 final

Germany, Slovakia and Sweden), Nickel (Austria, Finland, France, Greece, Poland, Spain and the United Kingdom); assess the potential in the whole EU for sourcing of secondary raw materials; put forward recommendations aimed at optimalising the sourcing of batteries raw materials within the EU."

It identifies the need to improve our knowledge on battery raw materials. Data regarding minor metals, as cobalt or lithium, is either unavailable, scattered, confidential or of low quality. Data in the EU is also reported under different standards, which makes their comparison and integration difficult.

It confirms that the EU is sourcing primary battery raw materials mostly from third countries such as Democratic Republic of Congo, Russia, Chile and Brazil, and that there is a potential for boosting primary and secondary battery materials production in the EU. It also shows that there are few obstacles to using the EU potential such as: the lack of geological data necessary to discover deeper deposits; the difficulty to access to known deposits; a weak integration of land use planning and mining and finally diverse regulatory conditions across the EU and low public awareness of raw materials and acceptance of production operations.

Chapter 6 of the report gives an overview of most relevant policy and regulatory framework at the EU level and in Member States, in particular the mining permitting issues. This should facilitate a structured and informed dialogue with Member States with the final objective to unlock the mining and recycling potential of battery raw materials within the EU.

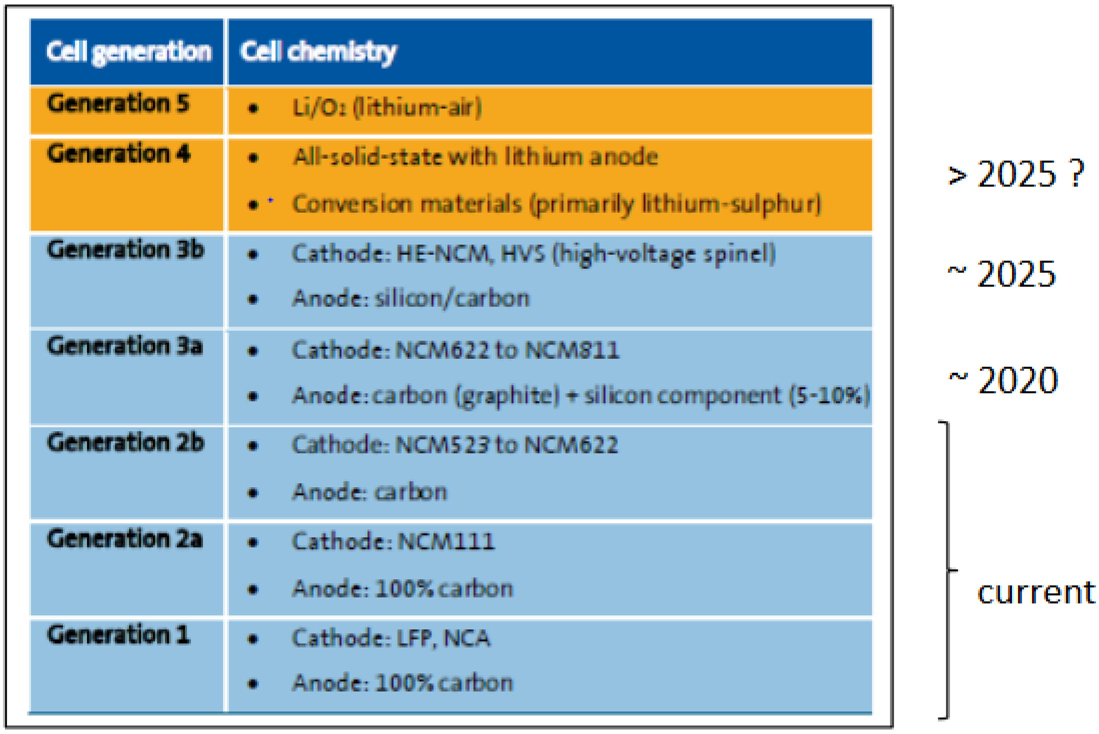
Finally, last chapter highlights the main issues to be considered in line with actions included in the Strategic Action Plan for Batteries.

2. BATTERY RAW MATERIALS OVERVIEW

2.1. Which are the key raw materials in batteries?

Lithium Ion Batteries (LIB), cells chemistries are classified using the general terminology "Generations" (see Figure 1). At present, optimised LIB cells of generation-1 and -2a represent the core technology for electric vehicles and for energy storage. Given the lead-time from R&D on battery materials to their actual incorporation in large-scale production of cells, these generations – and incremental improvements to them – are expected to remain the chemistry of choice for at least the next few years[5] .

As outlined in Figure 1 and in the Implementation Plan of the SET-Plan Action 7[6], efforts for establishing manufacturing capacity in Europe will primarily target LIB cells of generation-2b and beyond.[5]



Cell generation	Cell chemistry
Generation 5	• Li/O$_2$ (lithium-air)
Generation 4	• All-solid-state with lithium anode • Conversion materials (primarily lithium-sulphur)
Generation 3b	• Cathode: HE-NCM, HVS (high-voltage spinel) • Anode: silicon/carbon
Generation 3a	• Cathode: NCM622 to NCM811 • Anode: carbon (graphite) + silicon component (5-10%)
Generation 2b	• Cathode: NCM523 to NCM622 • Anode: carbon
Generation 2a	• Cathode: NCM111 • Anode: 100% carbon
Generation 1	• Cathode: LFP, NCA • Anode: 100% carbon

Figure 1. Classification of LIB cell chemistries7

The abbreviations reported in the above classification correspond to the following chemical names:

- For the cathode: LFP for $LiFePO_4$; NCM for $LiNiCoMnO_2$ and NCA: $LiNiCoAlO_2$
- For the anode: carbon (graphite) and silicon (Si).

---

[5] M.Steen, N.Lebedeva, F. Di Persio, L.Boon-Brett, EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions, JRC Science for Policy report, Petten, 2017.

[6] https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf

[7] Nationale Plattform Elektromobilität: Roadmap integrierte Zell-und Batterieproduktion Deutschland, Jan. 2016

And, the numbers refer to the stoichiometry of the compounds for example NCM 622 corresponds to $LiNi_{0.6}Co_{0.2}Mn_{0.2}O_2$. It is worth noticing that there is an overall tendency to try to decrease the amount of cobalt (what is called optimised cathodes) – the element of main concern today.

Supply of critical raw materials for LIB is ensured by working along the three routes: sourcing from third countries; developing domestic sourcing and promoting recycling of battery materials as well as reuse of batteries.

Global production

The sourcing of the four essential battery raw materials (see figure 2) is very concentrated in only few countries. This is particularly the case for natural graphite with 69% of the global supply from China and cobalt with 64% of global supply from Democratic Republic of Congo.

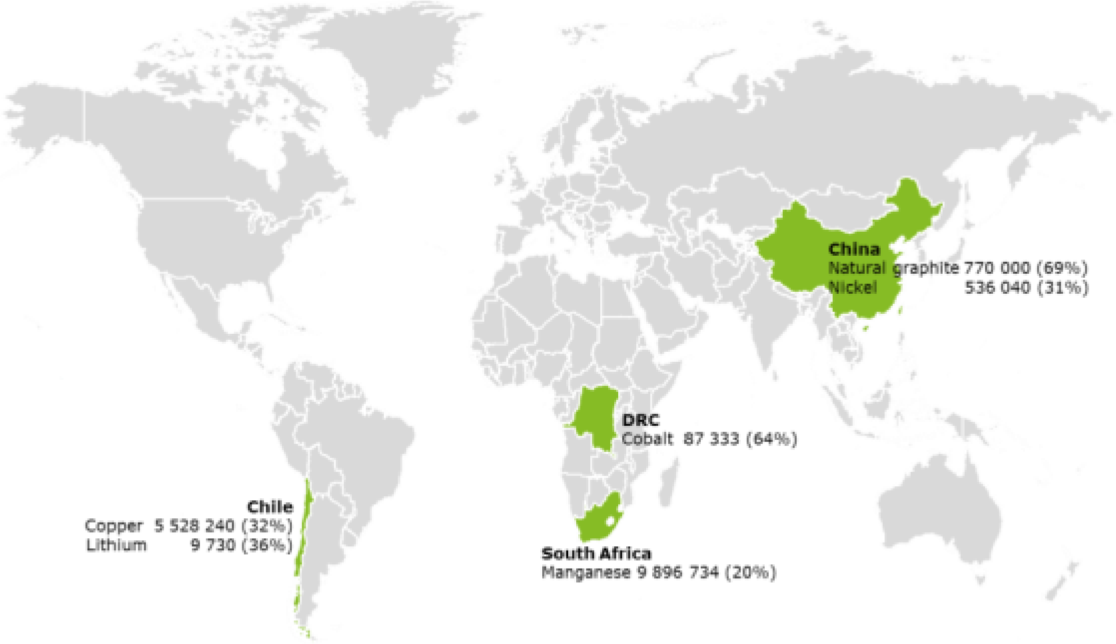


Figure 2: Countries accounting for largest share of global production of battery materials (tonnes, percent of global supply).8

China dominates global production of natural graphite and of silicon metal and steadily increases its control of mined cobalt mine production (as well as refined cobalt. Moreover, whereas lithium itself is not considered a critical material for the EU, China hosts the majority of the world's lithium refining facilities. As a result, China has acquired and is still expanding its dominant position in the LIB supply chain.

2.2. Sourcing to the EU

Looking at current countries accounting for largest share of EU supply of battery materials provides a completely different picture (see figure 3.). China remains the main supplier of natural graphite - the critical element of the anode and Chile is the main supplier of lithium. The only EU country, Finland is a major supplier of refined cobalt, in all cases with tonnages corresponding to 66% of EU demand for ores and concentrates.

---

[8] Study on the review of the list of Critical Raw Materials, June 2017

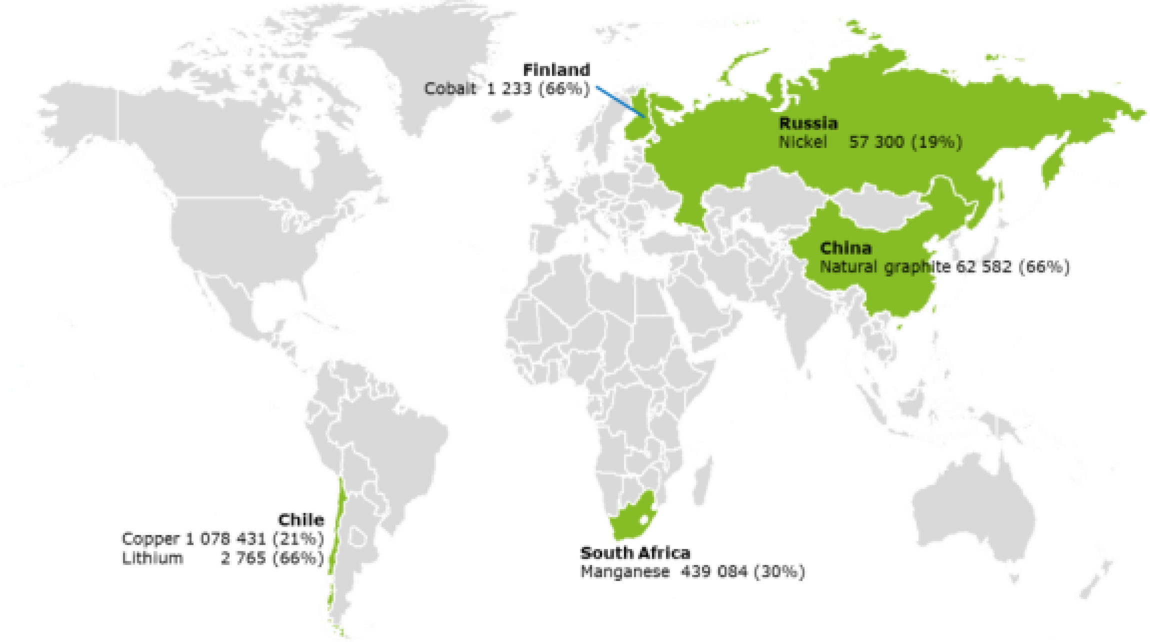


Figure 3: Countries accounting for largest share of EU supply of battery materials (tonnes, percent of EU supply). 9

Figure 4 provides a focus on mines' production and potential of battery raw materials in the EU. Apart from cobalt (mainly in refined form), coverage of EU demand by domestic sourcing is very limited for the other materials such as nickel, natural graphite, manganese and lithium.

Currently, sourcing of raw materials is mainly driven by prices. EU production of certain material may not yet be competitive, even if the deposits exist.

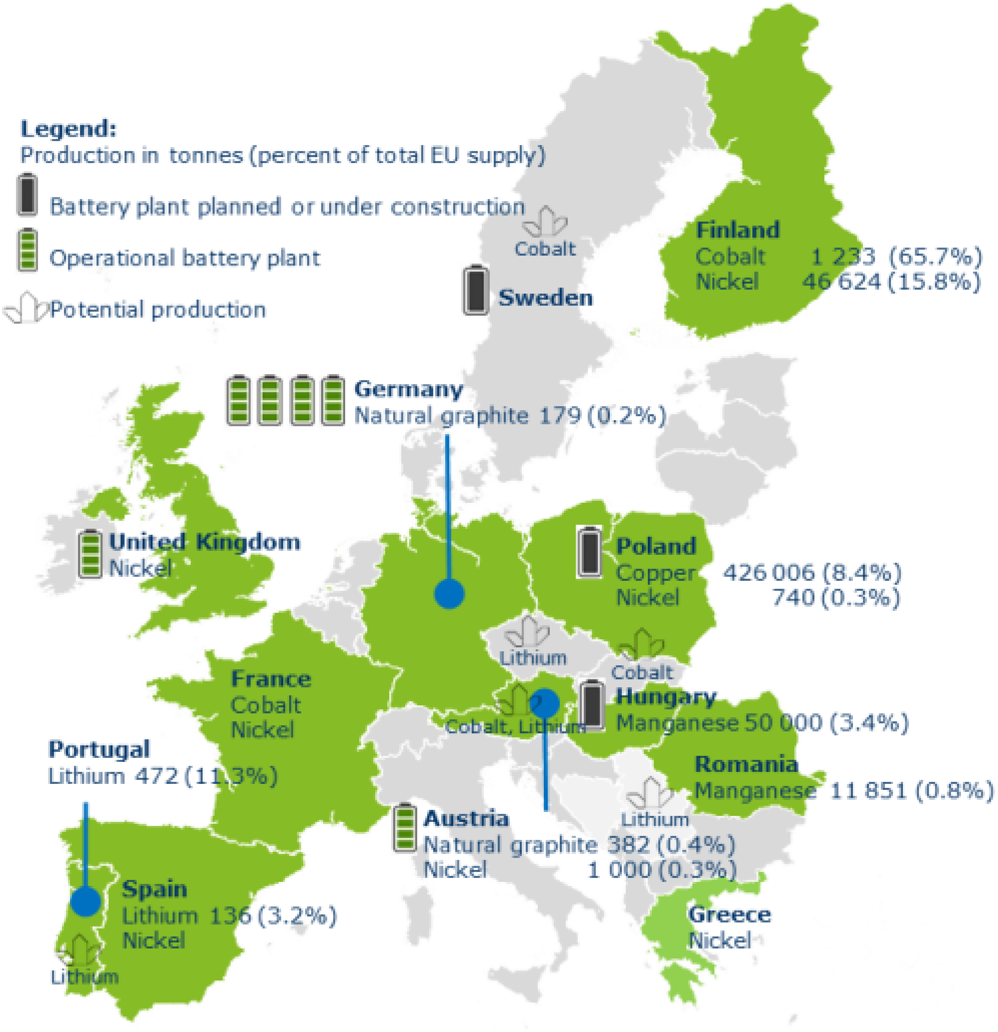
In some cases, such as lithium, lower price at the global market may be a result of objectively lower production costs, where the production costs from brines (Latin America, China) are approximately half of the production from hard rock (Australia, Canada, China and also Portugal[10]) which is relevant type of deposit in the EU (Austria, Czech Republic, Portugal, Spain etc.).

However, in case of environmental or social dumping when producing other battery raw materials in some of the third countries, the price difference would become less economically justifiable, while also creating supply risk for the EU downstream industry.

---

[9] Study on the review of the list of Critical Raw Materials, June 2017

[10] The production of one tonne of lithium carbonate from pegmatites in Portugal costs 4450 EUR, while the price for a ton from brine costs only around 1780 EUR on average. http://lithium.today/lithium-supply-by-countries/lithium-supply-portugal/



Source: EU Criticality assessment 2017

Figure 4: Mine production and potential of battery raw materials, and battery plants in the EU[11]

2.3. Alternative materials

Depending on the battery chemistry, the main critical raw materials (CRMs) currently embedded in batteries are antimony, cobalt, natural graphite, indium and some rare earth elements (see Figure 5). Antimony is mainly use for lead-acid batteries, and its use has declined due to new battery technologies[12]. In contrast, in recent years the battery market has seen a relative increase in the amount of cobalt: from 25% of global end uses of cobalt in 2005 to 44% in 2015[13]. Concerning natural graphite, almost 10% of worldwide uses of graphite in 2010 was for the batteries sector[14,15]. In fact, battery-grade graphite is widely used in several rechargeable and non-rechargeable batteries (both

---

[11] Study on the review of the list of critical raw materials – Critical raw materials factsheets, June 2017

[12] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[13] Study on the review of the list of Critical Raw Materials, June 2017

[14] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[15] Labie R. et al. (2015). "Recuperation of critical metals in Flanders: Scan of possible short term opportunities to increase recycling", available at https://steunpuntsumma.be/nl/publicaties/recuperation-of-critical-metals-in.pdf

portable and industrial) as anode. In the quickly growing Li-ion battery market, graphite is also favoured for anodes[16]. From 2010 to 2017, alkaline batteries accounted for about 5% of indium consumption.[17] Finally, among rare earth elements, 10% of the worldwide lanthanum and 6% of cerium are used for NiMH batteries.[18]

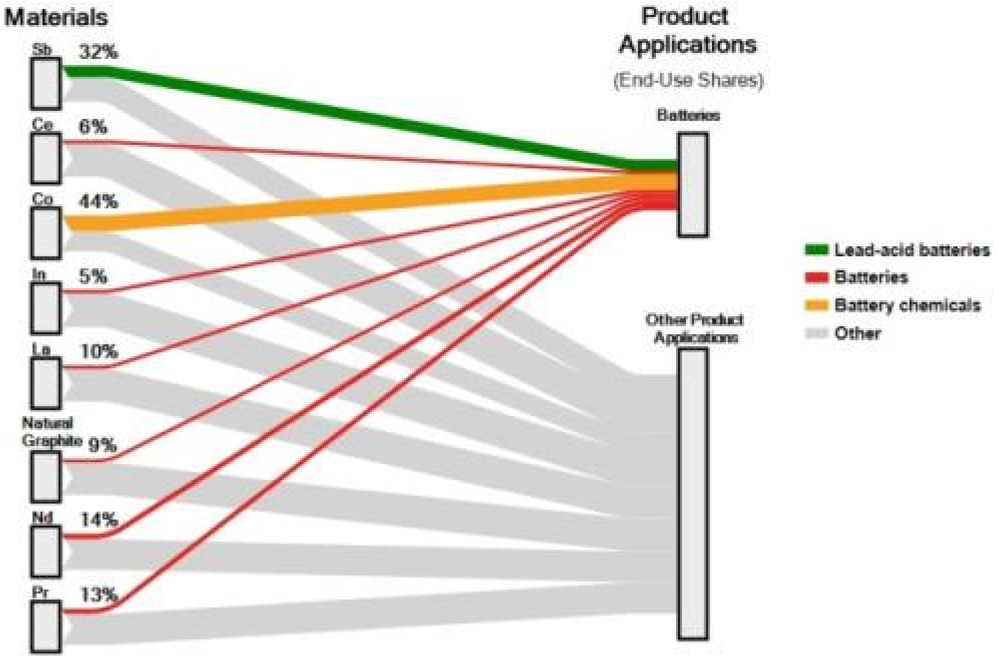


Figure 5: Flow of CRMs into battery applications according to the 2017 CRM assessment.

Besides the four materials lithium, cobalt, nickel and graphite, which are analysed in details in this report, there are a number of elements which deserves attention and which should be considered for further analysis of supply risk, namely manganese, tin, silicon, magnesium, germanium (all used in cathodes or anodes materials) and rare earth elements - REEs (used in nickel metal hydrides batteries and in large high performance neodymium-iron-boron magnets for Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EV) electric motors).

The application of these elements in batteries is still relatively low (for example, 2% of global manganese production is used in batteries) but demand for some of them could grow rapidly if they become the materials of choice in the next generations of batteries. Cobalt, graphite, and rare earths employed in Li-ion batteries and electric motors are among the most targeted by increasing EVs demand. Most of these elements are included in the 2017 criticality assessment and a factsheet is available for each one of the element mentioned above[19,20].

There are a wide range of different Li-ion battery technologies available and all of these could be considered as potential substitutes for the varieties that contain the most critical element at present: cobalt. The most commonly known type are lithium-nickel-oxide, lithium-manganese-oxide and

---

[16] EC, 2015. “Report on Critical Raw Materials for the EU critical raw materials profiles”, available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[17] Indium Corporation (2013), The Indium Market. 2017 CRM assessment

[18] 2017 CRM assessment

[19] Study on the review of the list of critical raw materials – Critical raw materials factsheets, June 2017

[20] Study on the review of the list of critical raw materials – Non-critical raw materials factsheets, June 2017

lithium-iron-phosphate. For the time being, in all of these potential substitutes the performance is considered to be lower than for the battery types that contain cobalt.

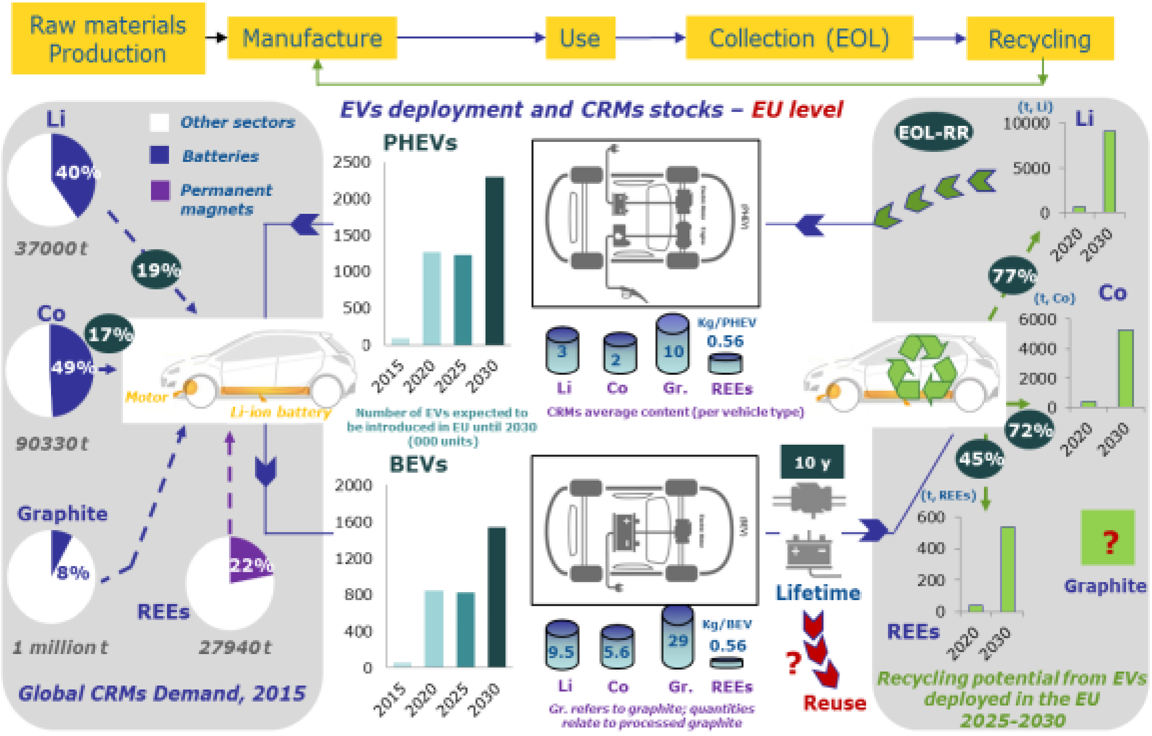


Figure 6. Use of selected raw materials (including CRMs) in the EVs sector (battery electric vehicles (BEVs), plug-in hybrid vehicles, (PHEVs)) and potential flows resulting from recycling of EVs deployed in the EU[21]*.*

The use of relevant materials in the EVs sector is depicted in Figure 6. It highlights again the importance of rare earth elements as critical elements for electric motors. The increase in demand of CRMs by 2030 is also very clear from Figure 7.

---

[21] Data sources are given in JRC, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecksalong-materials-supply-chain-future-deployment-low-carbon

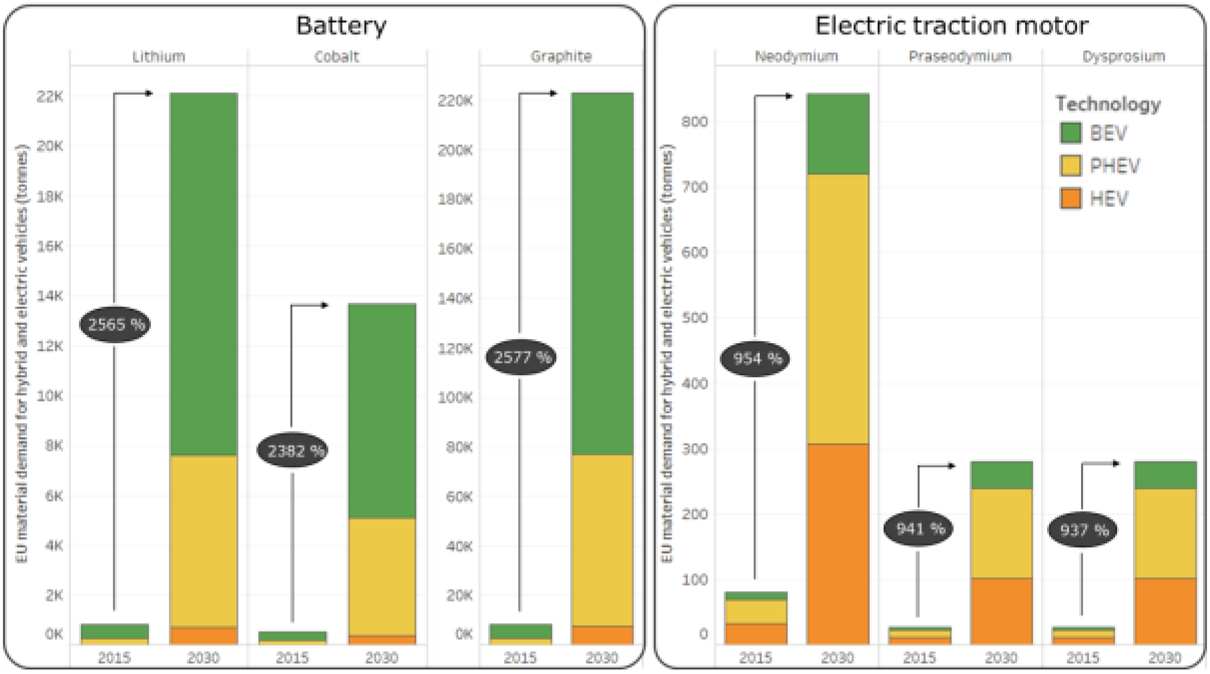


Figure 7: Demand forecast in the EU for selected Raw Materials (including some CRMs) for the hybrid and electric vehicles segments (BEV: battery electric vehicle; PHEV: plug-in hybrid electric vehicle; HEV: hybrid electric vehicles).

3. BATTERY RAW MATERIALS MARKET

Markets of battery raw materials can be very dynamic in the short term. As shown on Table 1 below and in the corresponding long-term prices graphs hereafter, the prices are volatile in a short but also in a longer term. However, the prices affect the production only to a relatively small extent. The production of cobalt, lithium, nickel and graphite has been slightly increasing over the last 50 years, and accelerating in the last decade.

When making any judgement on the future market of raw materials, it is important to look at the long term trend over several decades, rather than on the last few year's statistics. Long term trends reflect markets evolution during periods of technological breakthroughs and their uptakes in electronics, energy or other fields.

In addition to the unpredictability of the demand, other factors induce price volatility, such as the rigid supply structure, slow reaction to demand increases, lack of supply diversification, etc…. For illustration, Table 1 shows the price volatility of selected raw materials from year to year. The long-term graphs hereafter show that the supply is not very elastic. The price peaks therefore reflect longer term demand pressure.

Table 1: Average prices and price volatility of selected battery raw materials[22]

	Commodity	Period	Average price	Price volatility
COBALT	LME, min. 99.3 %, cash, in LME warehouse	03/2017 – 02/2018	62.450,9 US$/t	21,7 %
		01/2013 – 12/ 2017	33.480,2 US$/t	20,2 %
LITHIUM	Spodume concentrate, >7.5 % LiO2, bulk, cif Asia	03/2017 – 02/2018	875,6 US$/t	17,2 %
		01/2013 – 12/ 2017	-	-
NICKEL	LME, primary, min. 99.8 %, cash, in LME warehouse	03/2017 – 02/2018	10.890,9 US$/t	22,2 %
		01/2013 – 12/ 2017	12.742,4 US$/t	20,8 %
GRAPHITE	Crystalline large flake, 94-97 % C, +80 mesh, cif main European port	03/2017 – 02/2018	901,4 US$/t	21,9 %
		01/2013 – 12/ 2017	1.122,1 US$/t	16,8 %

Cobalt

Prices of cobalt (see Figure 8.) are available for two main grades 99.80% (high grade) and 99.30% (low grade). Cobalt production (see Figure 9) has been steadily growing over the last 50 years and even accelerating since 2000's. The price has also been growing, however it has been strongly influenced by supply (crisis in DR Congo) and demand (from Asia) disruptions. The cobalt prices peaked in 2008 reaching almost €80 ($120) per kg. After a sharp decrease in 2009-2016, the prices again quadrupled in the last two years, reaching again around €80 ($90) per kg in 2018.

---

[22] DERA, Volatilitätsmonitor März 2017 – February 2018

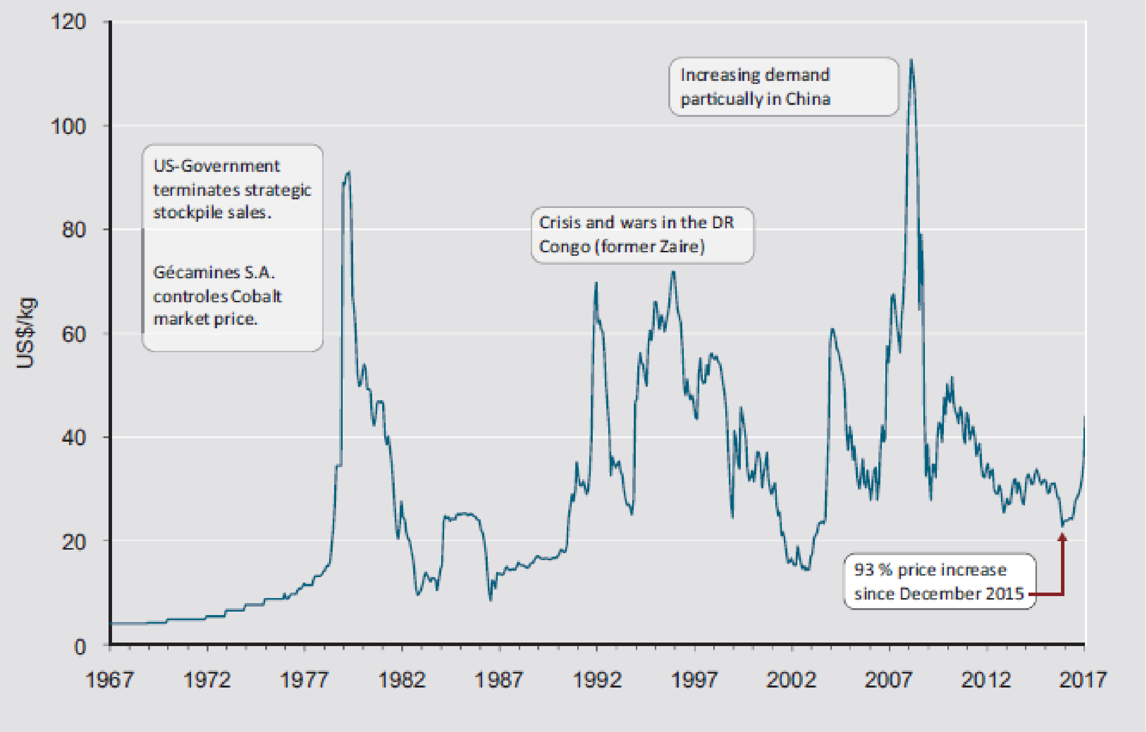


Figure 8: Mean monthly cobalt price (99.8 % free market) from 1967 to February 2017 (BGR 2017[23]).

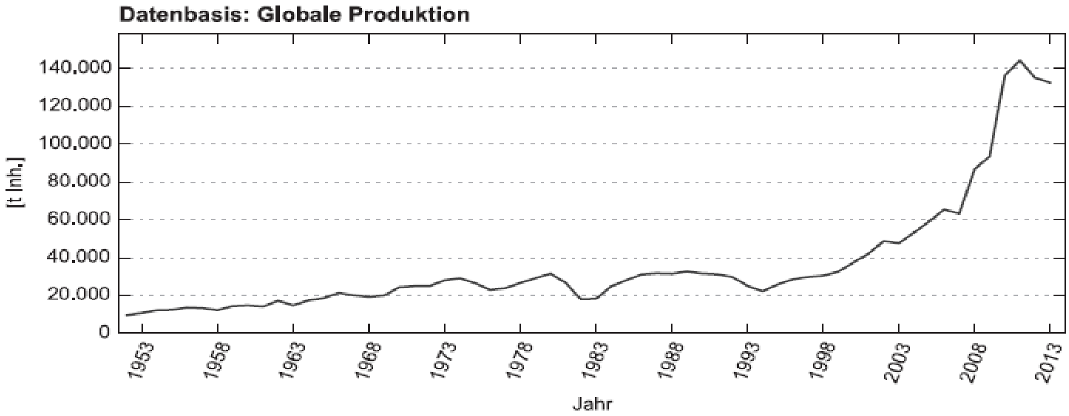


Figure 9: Cobalt global production (content of cobalt in tonnes, year), DERA[24]

Lithium

The prices of lithium (see Figure 10.) have dropped in 2001 but increased since 2005 to recover their 2000's value of about 4.500 dollar per tonne (USGS, 2016a). Prices have tripled between 2005 and 2008, and stabilised for several years. According to the DERA raw materials price monitor and the LMB Bulletin, lithium carbonate prices have again increased since 2015 from a cost of 6.222 US$/t in average over the period 2011-2015 to 7.091 US$/t in average over the period December 2015 - November 2016, i.e. a price increase of 14%.

---

[23] BGR (2017): Cobalt from the DRC – Potential, Risks and Significance for the Global Cobalt Market (translated, original in German). Commodity Top News v. 53, Hannover.

[24] Wachstumsraten-Monitor Entwicklung von Angebot und Nachfrage ausgewählter mineralischer Rohstoffe, DERA, 2016

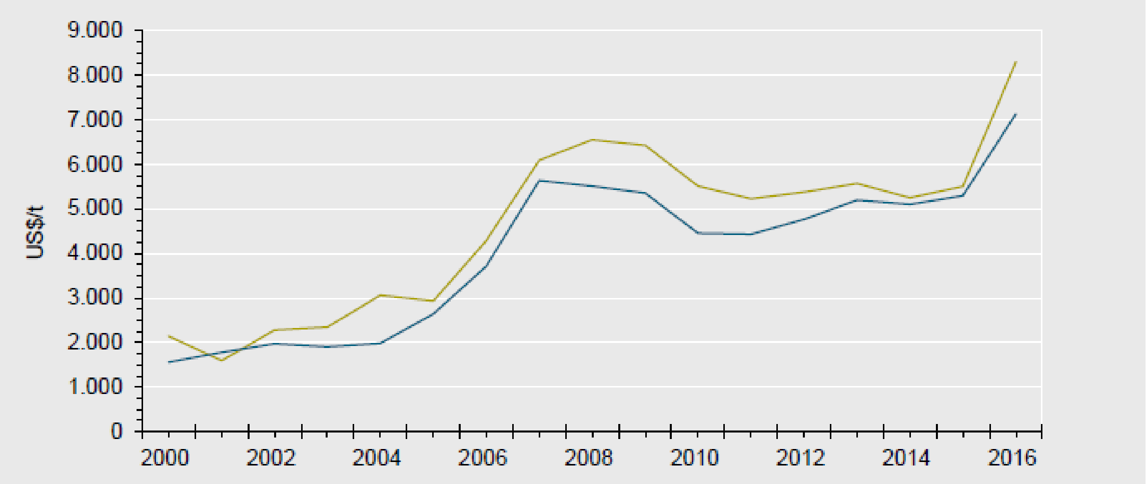


Figure 10: Lithium carbonate annual average prices between 2000 and 2016 (yellow for "battery grade", blue for "technical grade"), DERA

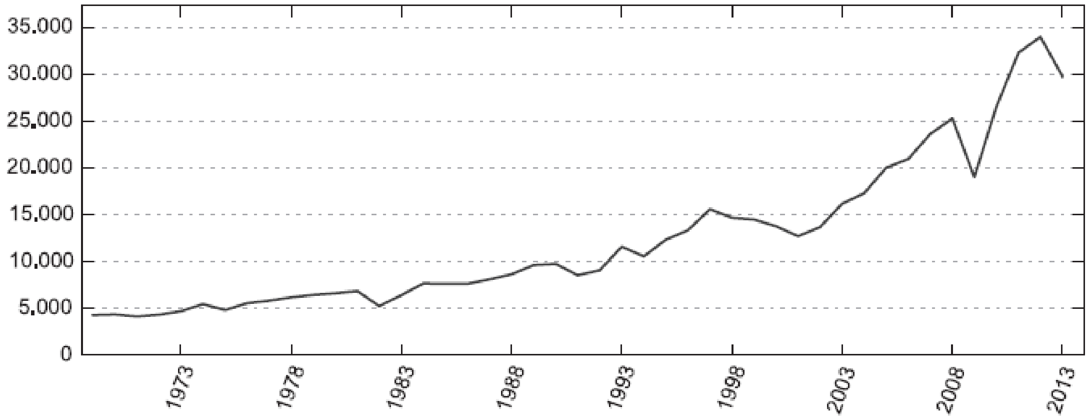


Figure 11: Lithium ores global production (content of lithium in tonnes, year), DERA

Nickel

Different supply and demand situations worldwide influenced nickel prices during the last century. Overall, production and prices had been rising during that period (see Figure 12 and Figure 13), but price peaks had been induced or increased several times by strikes in Canada – with the last strong price peak induced by both strikes in Canada and a high demand in Asia. The average price of primary nickel (>99.8%) on the London Metal Exchange between 2011 and 2015 was 16.827,82 US$/t (DERA, 2016).

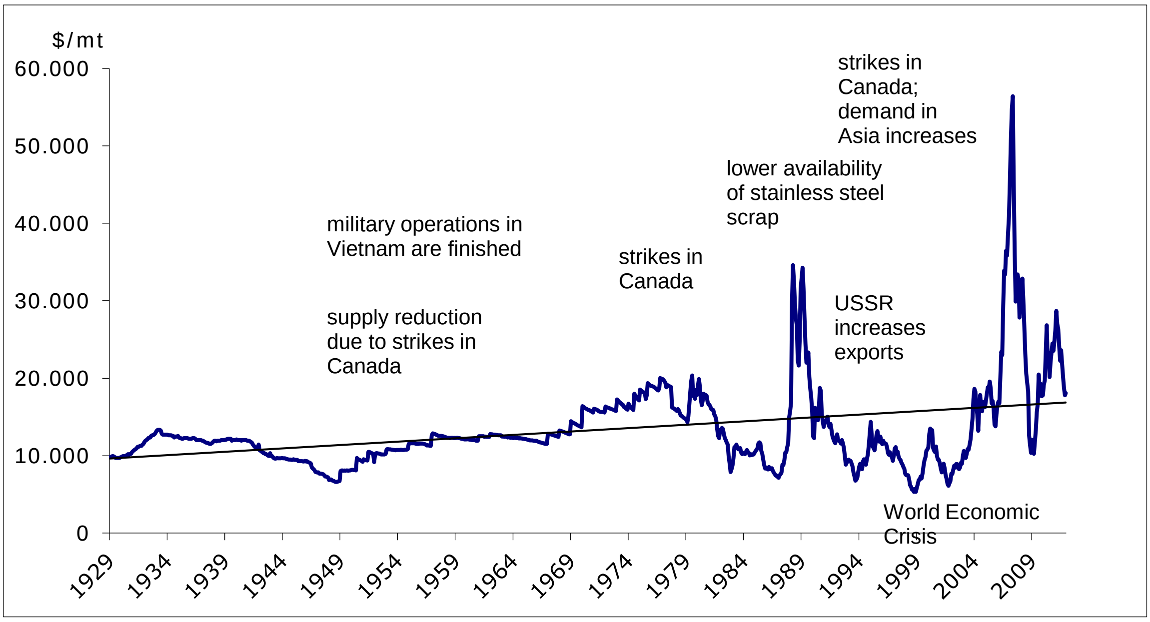


Figure 12: Development of real nickel prices (constant prices 2011 = 100), DERA

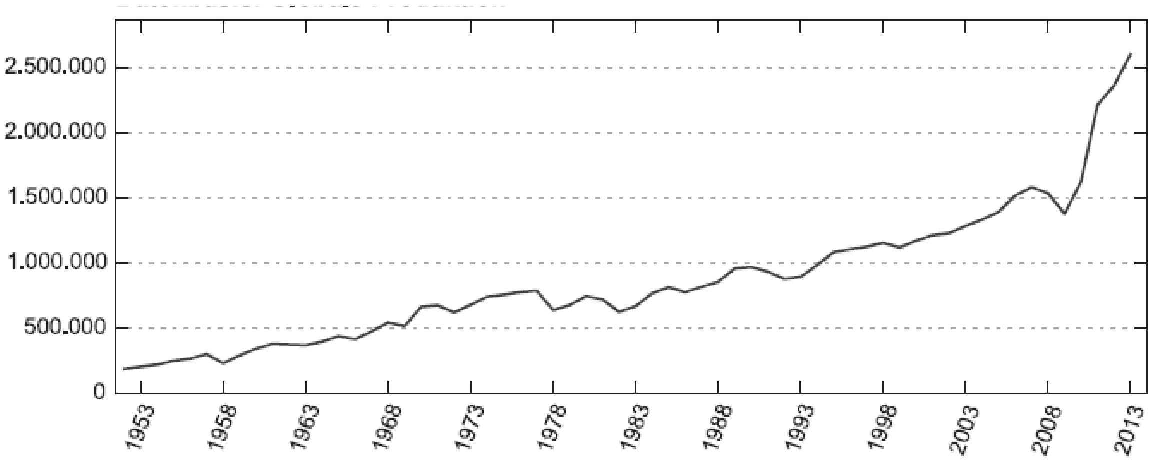


Figure 13: Nickel ores global production (content of nickel in tonnes, year), DERA

Natural graphite

The two most important parameters of natural graphite pricing are carbon content and mesh size (the size of the grains) which both depend on the natural forms of graphite (amorphous, flake and vein). Larger and purer flakes present higher prices. Transport, specifically sea freight, can account for up to 30% of the total price. Outside of China, the price is set by the negotiations between the larger mining companies and the major refractory manufacturers. In China, the flake graphite price is set by producers in Shandong and Heilongjiang while amorphous graphite price is controlled by the government-run company that produces about 90% of the world's supply, in Hunan province[25].

---

[25] http://www.indmin.com/Graphite.html

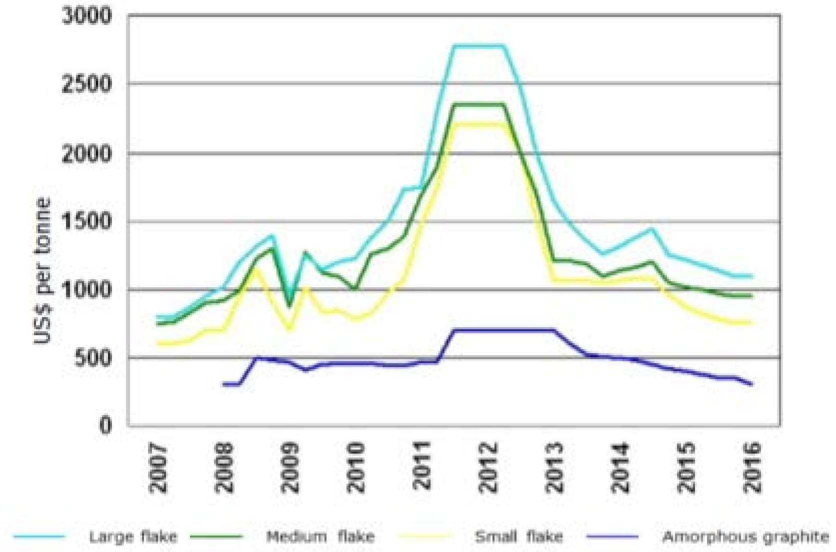


Figure 14: Amorphous and flake graphite prices. (Mason Graphite, 2017)

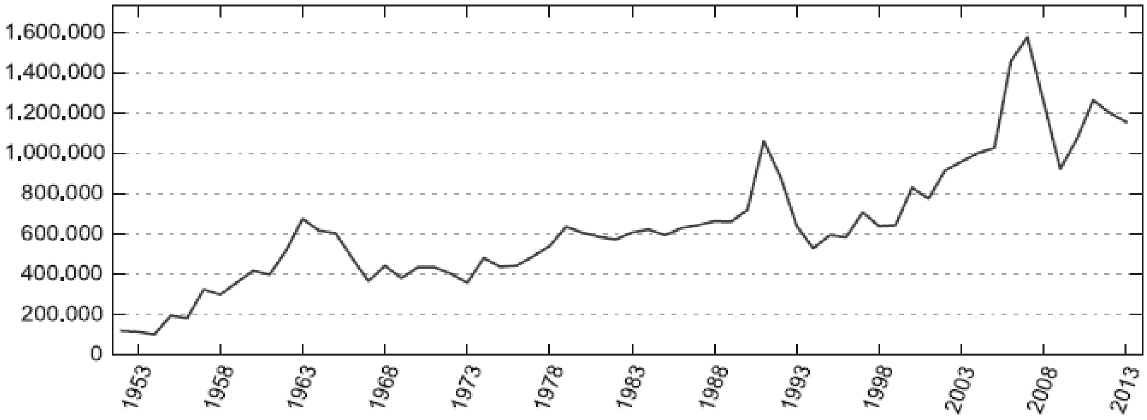


Figure 15: Graphite global production (tonnes, year), DERA

Flake graphite prices remained relatively stable for many years until 2005, after which they climbed gradually to 2008, before declining in 2009 following the global financial crisis. Due to China's huge steel needs, flake graphite prices soared in 2011-2012 but have since returned to 2008 levels due to excess production and reduced demand from the steel industry (Figure 14.). Amorphous prices are much lower (less than 500 US$/t). Uncoated spherical graphite for use in lithium-ion batteries is currently around 3.000 US$/t, having decreased slightly during 2015. Coated spherical graphite commands significantly higher prices (7.000 US$/t or more).

4. FUTURE OUTLOOK

4.1. Future demand

Making a forecast is always a difficult exercise but one of the prevailing scenario[26] corresponds to a global battery production of nearly 500 GWh by 2025 (from 120 GWh in 2017 of global battery sales). As outlined on Figure 16 a large increase of metals will be needed for rechargeable batteries – 3 times

---

[26] source Avicenne Energy 2018

for cobalt with a demand by 2025, surpassing the actual 2018 global production and 3.5 times for lithium representing 75% of the global production by 2025.

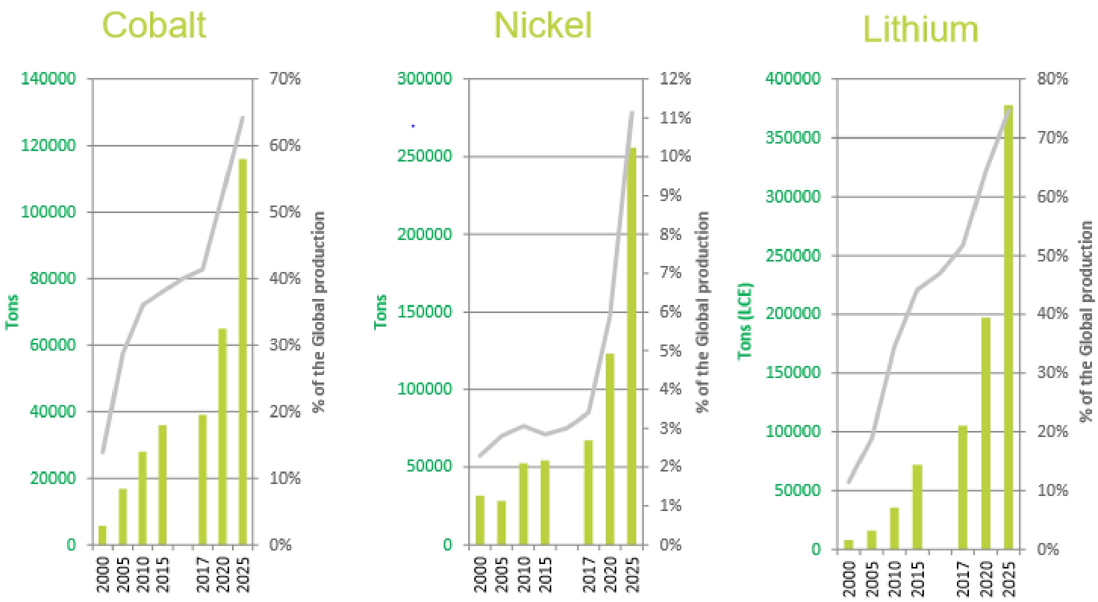


Figure 16: Metals demand for rechargeable batteries[27]

According to one of the latest market outlook[28], the cobalt supply chain is at risk because of political instability and concentration in the Democratic Republic of Congo Other factors could also affect supply chain; e.g. refining of cobalt predominantly taking place in China, the rapid increase in the demand and inflexibility of the supply to cope timely and in adequate manner with such increase.

The lithium supply chain has difficulty to meet battery sector demand. However, the situation could be less critical in the future, because some companies have announced a ramp-up of their production capacity. However, processing capacity of battery-qualified grade materials (lithium carbonate and lithium hydroxide monohydrate) will remain a bottleneck in the years to come.

The situation is more relaxed with regard to the nickel supply chain. Today only, 2-3% of global production e.g. 394.000 t, is going to batteries and in addition, nickel production occurs in nearly 40 producing countries. However it is worth to mention that most nickel in the global supply chain is not suited for battery production therefore there is an issue in term of capacity to produce battery grade nickel (Ni sulphide). The possibility to ramp-up production relatively quickly could reduce this bottleneck.

Building up and strengthening EU activity in battery material supply is imperative to reduce the EU future dependence on imported battery component materials for cell manufacturing.

4.2. Will supply meet the demand in the future?

Last year was a turning point for batteries' development and production. Vehicle manufacturers have been announcing new electric models and new strategies. Batteries will be important not only for e-

---

[27] source Avicenne Energy 2018

[28] Li-ion batteries and the years ahead. Martim Facada. Industrial Minerals 22 February 2018

mobility but will also be a key to respond to the challenges of the EU Energy Union, for example, for the integration of renewables into the grid through electricity storage.

Table 2: Forecast of supply and demand of battery raw materials [29]

Material	On the EU CRM list 2017?		Demand forecast			Supply forecast			Future demand vs. Current supply	
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years	5 years[30]	20 years[31]
Cobalt	x		+	+	+	+	+	+	1.30x	0.9x
Lithium		x	+	+	?	+	+	?	1.37x	3.9x
Natural graphite	x		+	+	+	+	+	+	1.20x	-
Nickel		x	+	++	++	++	+	+	-	-

+ stands for expected slight to moderate increase in demand, ++ for expected high increase in demand

Table 3: Short-term estimates of raw material need for lithium batteries in 2020[32]

	Battery needs	Lithium	Cobalt	Graphite Carbon
	GWh (times 2015 production)	Ton (times 2015 production)	Ton (times 2015 production)	Ton (times 2015 production)
Electric vehicles	100 (1,33x)	16.000 (0,5x)	11.000 (0,11x)	100.000 (0,26x)
Consumer electronics	40 (0,53x)	6.400 (0,20x)	57.600 (0,58x)	40.000 (0,11x)
Stationary	10 (0,13x)	1.600 (0,05x)	1.800 (0,02x)	10.000 (0,03x)
Li battery total	150 (2,0x)	24.000 (0,75x)	70.400 (0,71x)	150.000 (0,40x)
Other uses		20.700	58.000	306.000
Total needs		44.700 (1,37x)	128.400 (1,30x)	456.000 (1,20x)

It is expected that the demand for batteries will rise exponentially in the next 7-10 years. In the longer term, the improved resource efficiency and technology shift may reduce the demand for the selected materials.

In 2015 Li-ion batteries consumed around 40 % of the global Lithium Carbonate Equivalent (LCE[33]), production, of which 14% was used for electric vehicle battery packs. Projection for 2025 shows that electric vehicle demand alone will utilise 200,000 tons of LCE, which equates to the total current

---

[29] Study on the review of the list of Critical Raw Materials, Critical Raw Materials Factsheets, June 2017

[30] Demand in 2020 vs. supply in 2015 (Pertti Kauranen, Closeloop, Raw material needs by the Li-ion battery industry, 17 May 2017)

[31] Demand in 2035 vs. supply in 2013 (DERA study, Raw materials for emerging technologies 2016)

[32] Pertti Kauranen, Closeloop, Raw material needs by the Li-ion battery industry, 17 May 2017

[33] 1 kg LCE = 0.1895 kg lithium

global LCE supply. Known lithium reserves are sufficient to cope with this foreseen increase in demand even without recovery of lithium from the recycling of Li-ion batteries. However, only few lithium processors have the capacity and ability to produce the very high-grade lithium compounds that batteries need. China[34] is stepping up its pursuit of control of the lithium supply chain, underpinned by the rapid growth of its lithium-ion battery industry building on policy surrounding electric vehicle sales.

Natural and synthetic graphite compete for use in lithium-ion batteries. Currently, all production of spherical graphite takes place in China close to both resources and markets. The majority of battery, anode, and anode material manufacture has now moved to China. Production costs are also lower and there are less environmental restrictions on the use of reagents.

---

[34] https://roskill.com/news/lithium-chinese-companies-step-up-their-pursuit-of-lithium-resources/

5. SUPPLY OF BATTERY RAW MATERIALS

5.1. Exploration, resources and reserves

Mineral exploration activities are ongoing across the EU (see Figure 17), though with remarkable differences among the Member States. The exploration budget increased in 2017 after a decreasing trend since 2012. Mineral exploration activities remain concentrated in Portugal, Finland, Sweden and central Europe, with besides the four elements for battery applications, gold, copper and zinc as the main targeted commodities.

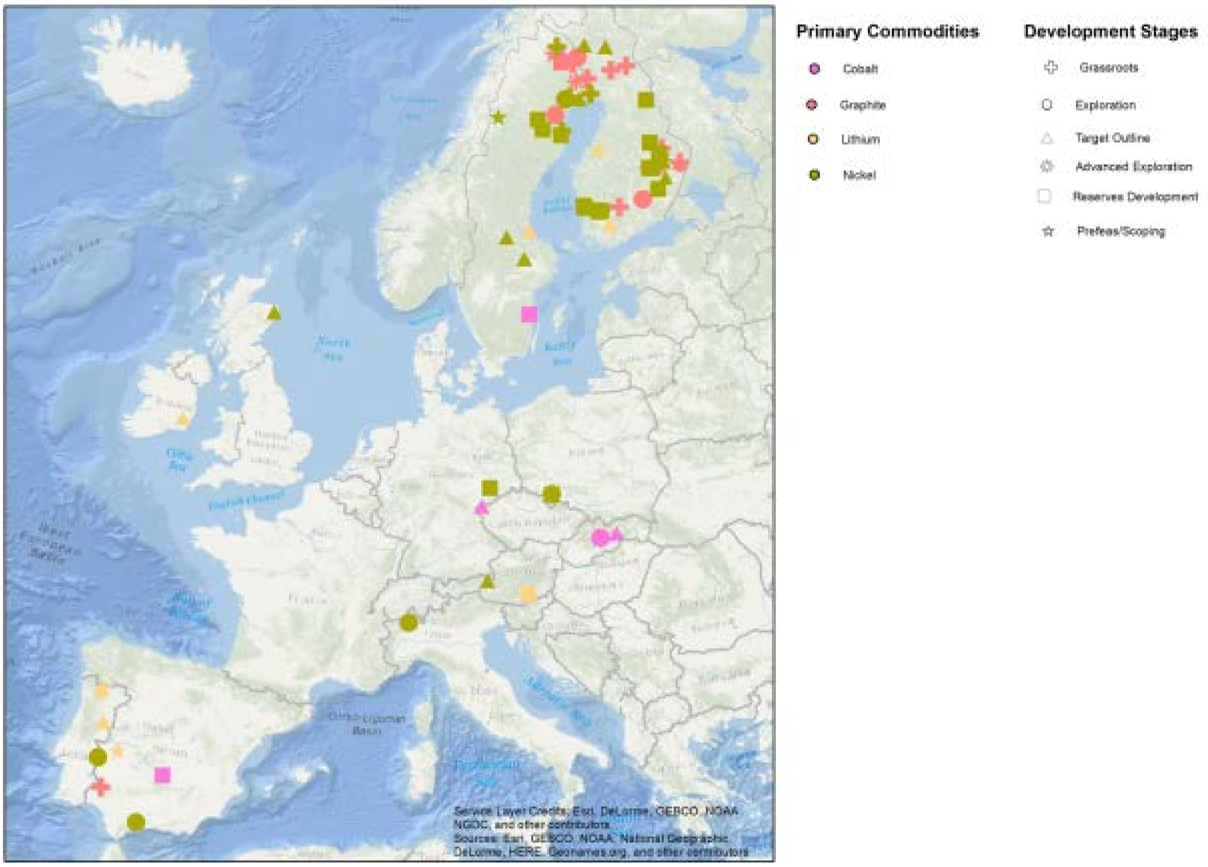


***Figure 17: Mineral exploration activities in the EU for cobalt, natural graphite, lithium and nickel (2017)*[35].**

For the EU, there is no complete and harmonised dataset that presents total EU resource and reserve estimates. The EU's funded project Minerals4EU[36] is the only EU-level repository of some mineral resource and reserve data. However, it includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets. This makes comparison and summing the data difficult. The INSPIRE Directive (2007/2/EC) is being more and more implemented in the raw material field to ensure consistency and comparability of data.

The United Nations Framework Classification for Resources (UNFC)[37] is an existing universal standard that can facilitate policy and strategy formulation, government resources management,

---

[35] Source: JRC elaboration from S&P Global Market Intelligence, 2017.

[36].http://www.minerals4eu.eu/

[37] https://www.unece.org/energywelcome/areas-of-work/httpswwwuneceorgenergysereserveshtml/applications/unfc-and-mineral-resources.html

industry business processes and capital allocation. Once operational and adopted by a sufficient number of countries and EU Member States, it would allow integrating the data from the reporting standards used in the EU.

Resources

The global resources estimated in Table 4 below come from the United States Geological Survey. The estimates are only valid for today - with further exploration the amount of resources will grow in time.

Table 4: Most important global resources - natural concentrations of minerals[38, 39]

Country				
	Cobalt (t)	**Lithium (t)**	**Nickel (t)**	**Graphite (t)**
Argentina		✔		
Australia	✔	✔	✔	
Bolivia		✔		
Brazil	✔	✔	✔	✔
Canada	✔	✔	✔	✔
Chile		✔		
China	✔		✔	✔
Colombia			✔	
Cuba	✔		✔	
Dem. Rep. of Congo	✔	✔		
Guatemala			✔	
India				✔
Indonesia			✔	
Madagascar			✔	✔
Mexico		✔		✔
New Caledonia (France)	✔		✔	
Norway				✔
Philippines	✔		✔	
Russia	✔	✔	✔	✔
South Africa	✔		✔	
Serbia		✔		
Turkey				✔
Ukraine				✔
United States of America	✔	✔	✔	✔
Zambia	✔			
Zimbabwe				✔
Other countries				
World total (rounded)	**25.000.000**	**41.000.000**	**130.000.000**	**800.000.000**

---

[38] Estimated global reserves in 2015 (Data from USGS, 2016)

[39] BGS, NERC, 2016

Table 5: Resources of battery raw materials in the countries of the EU [40,41]

European Union 28	Cobalt	Lithium	Nickel	Graphite
Austria		✔		
Czech Republic		✔		✔
Finland	✔	✔	✔	
France	✔	✔	✔	
Germany	✔			✔
Greece			✔	
Ireland		✔		
Poland	✔		✔	
Portugal	✔	✔	✔	
Slovakia	✔		✔	✔
Spain	✔	✔	✔	
Sweden	✔	✔	✔	✔
United Kingdom			✔	

Cobalt is usually one of a suite of metals identified during exploration for polymetallic deposits. Within Europe, resources of cobalt are known to exist in Finland, Germany, Norway and Sweden but data for these deposits are not reported in accordance with the UNFC system of reporting. The Minerals4EU project identified in 2013 that exploration activities for polymetallic deposits (possibly containing cobalt) were undertaken in Poland, Portugal, Spain, Sweden and Greenland. Recent information from S&P/SNL database reports on drilling in Slovakia, Sweden, Czech Republic, Norway and Greenland. Data for Germany is not reported at all because data collection in that country is the responsibility of sub-national level authorities. Resources may also exist in other European countries but no information is available.

Lithium is found in nature in a number of mineral forms distributed well across continents. Global lithium resources have increased substantially to more than 53 million tons and reserves to 16 million tons[42].

Around half of the global resources and reserves are located in South America, notably in Argentina, Chile, Bolivia and Brazil. EU lithium resources are estimated at 0.4 million tons LME and reserves at 0,013 million tons LME.[43] Additionally, Serbia has unique deposits of jadarite (lithium sodium borosilicate mineral) with resources of over 1.1 million tons LME[44], which corresponds to almost 3% of the global resources.

Identified land-based resources averaging 1% nickel or greater contain at least 130 million tons of nickel, with about 60% in laterites and 40% in sulphide deposits. Extensive nickel resources also are found in manganese crusts and nodules on the ocean floor.

World's inferred resources exceed 800 million tons of recoverable graphite, reserves of natural graphite are estimated to be 230 million tons.

---

[40] Minerals4EU, 2014 (http://minerals4eu.brgm-rec.fr/)

[41] DERA, BGR

[42] USGS, 2018

[43] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, JRC Science for Policy Report, Petten, 2016, and references therein.

[44] http://www.riotinto.com/documents/170302_Increase_to_Jadar_Project_Mineral_Resources.pdf

Reserves

Mineral reserves are a part of “resources” known to be economically feasible for extraction at current conditions. Most of the data in Table 6 below come from the United States Geological Survey. The reserves can be expanded in the future, for example by new discoveries, new technologies able to process lower grades or by increased price of the raw materials.

Table 6: Global reserves - resources known to be economically feasible for extraction[45]

Country	Reserves							
	Cobalt (t)	%	Lithium (t)	%	Nickel (t)	%	Graphite (t)	%
Argentina			**2.000.000**					
Australia	**1.100.111**	**15**	**1.500.000**		**19.000.000**	**24**		
Brazil	78.000	1	48.000		**10.000.000**	**13**	**72.000.000**	
Canada	240.000	3			2.900.000	4		
Chile			**7.500.000**					
China	80.000	1	**3.200.000**		3.000.000	4	**55.000.000**	
Colombia					1.100.000	1		
Cuba	500.000	7			5.500.000	7		
Dem. Rep. of Congo	**3.400.000**	**48**						
Guatemala					1.800.000	2		
India							8.000.000	
Indonesia					4.500.000	6		
Madagascar	130.000	2			1.600.000	2	940.000	
Mexico							3.100.000	
New Caledonia (France)	200.000	3			**8.400.000**	**11**		
Philippines	250.000	4			3.100.000	4		
Russia	250.000	4			7.900.000	9		
South Africa	30.000	<1			3.700.000	5		
Turkey							**90.000.000**	
United States of America	23.000	<1	38.000		160.000	<1		
Zambia			270.000					
Zimbabwe			23.000					
Other countries	610.000	9			6.500.000		960.000	
World total (rounded)	7.000.000*		14.000.000		80.000.000*		230.000.000	

** Manganese nodules and cobalt-rich crusts on the sea floor are estimated to contain more than 120 million tonnes of cobalt and large quantities of nickel (USGS, 2016).*

---

[45] Estimated global reserves in 2015 (Data from United States Geological Survey - USGS, 2016)

Table 7: Economic reserves of battery raw materials in the countries of the EU[46]

European Union 28	Cobalt (t)	Lithium (t)	Nickel (t)	Graphite (t)
Austria			✔	✔
Czech Republic		✔		✔
Finland	✔	✔	✔	
France	✔		✔	
Germany			✔	✔
Greece			✔	
Ireland				
Poland			✔	
Portugal		✔		
Spain		✔	✔	
Sweden			✔	
United Kingdom			✔	

---

[46] Reserve data for the EU-28 in EU critical raw materials assessment 2017, from the European Minerals Yearbook (Minerals4EU, 2014)

5.2. Mining

The EU itself is using its own mineral potential to a small extent[47]. The EU remains a producer of several basic metals such as copper, lead, iron ore and precious metals (gold, silver, and platinum group metals). The EU also has mine production of several critical raw materials, such as tungsten, graphite, rare earth elements, phosphate, and vanadium.

Table 8: Production and sourcing of primary battery raw materials[48]

Raw materials	Major global producers	Major sources of EU supply	EU production	Import reliance rate	End-of-life recycling input rate
Cobalt	D.R. Congo (64%) China (5%) Canada (5%) 135 500t	Finland (66%) Russia (31%) 1 900t	Finland	32%	35%
Lithium	Chile (44%) Australia (32%) Argentina (11%) 25 500t	Chile (66%) Portugal (11%) United States (9%) 4 200t	Portugal Spain	86%	0%
Nickel	Indonesia (24%) Phillipines (16%) Australia (10%) Canada (10%) New Caledonia (7%) 2 255 500t	Russia (20%) Finland (16%) United Kingdom (13%) Norway (8%) 293 400t	Austria Finland France Greece Poland Spain United Kingdom	59%	34%
Natural graphite	China (69%) India (12%) Brazil (8%) 1 100 000t	China (63%) Brazil (13%) Norway (7%) 95 000t	Austria Germany	99%	3%

Cobalt

Cobalt is predominantly extracted as a by- or co-product of nickel or copper mining. Approximately 50% of global supplies of cobalt come from the nickel mining industry, whilst 44% is sourced from copper mining and only 6% from mining operations where cobalt is the primary objective.[49]

Globally, cobalt is mined in 19 countries with the largest producers being the Democratic Republic of Congo (with 64% of the global total, based on a five-year average over 2010-2014), China (6%) and Canada (5%). The world mine production of cobalt is about 135 thousand tonnes in average over the period 2010-2014. With relevance to the EU, 2% of global production is covered by New Caledonia (a Special Collectivity of France) and 1% by Finland.

---

[47] Raw Materials Scoreboard: https://publications.europa.eu/en/publication-detail/-/publication/1ee65e21-9ac4-11e6-868c-01aa75ed71a1/language-en

[48] EU critical raw materials assessment 2017, Study on Material System Analysis, MSA, 2015 and World Mining Data 2017. Production: 5 years average, typically 2010-2014

[49] Cobalt Development Institute

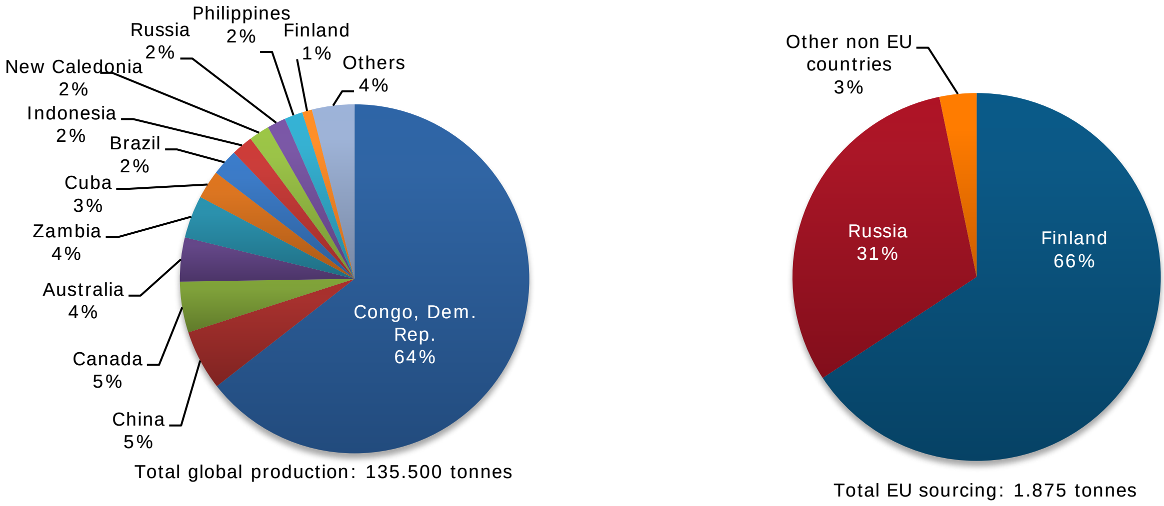


Figure 18: Global cobalt mine production and EU sourcing (domestic production + imports), average of 2010–2014

Global production countries profile changes with the time, DRC has only become a dominant producer in the last decade.

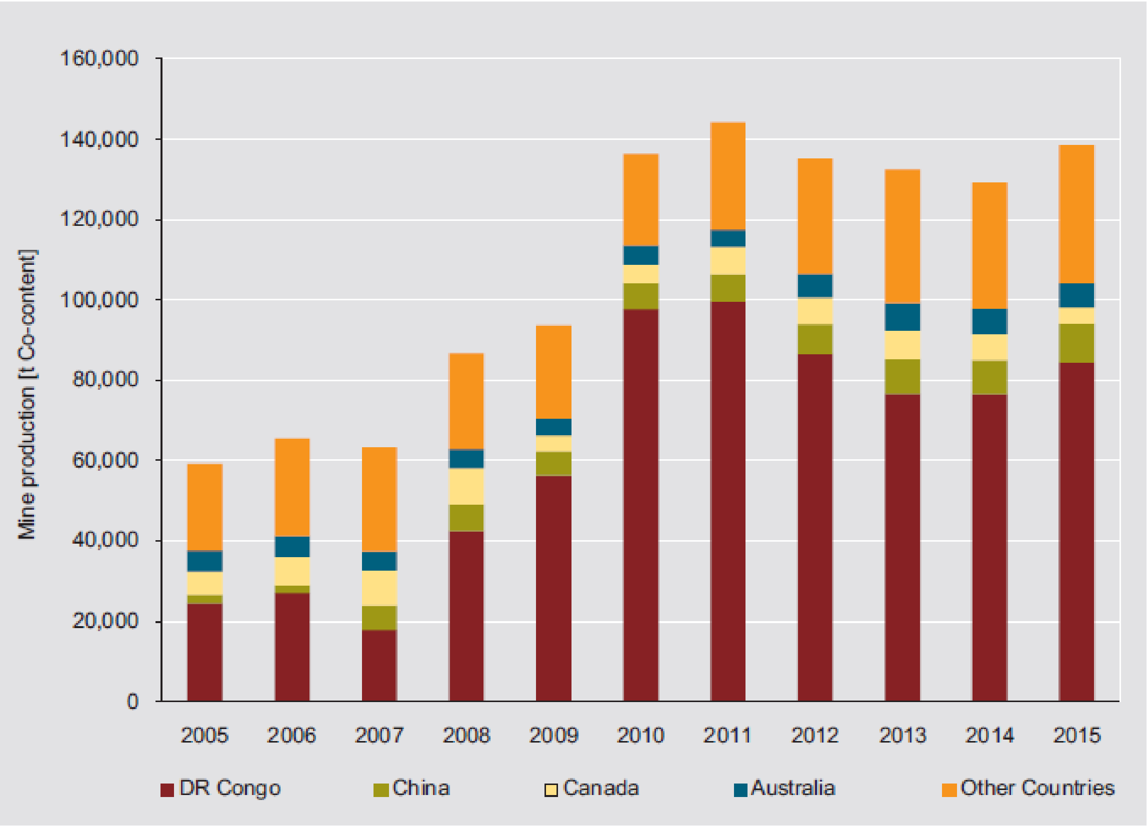


Figure 19: Cobalt mine production from 2005 to 2015 (DERA, BGR 2017).

In the EU, cobalt is only mined in Finland, where it is a by-product of nickel or copper mining in 4 mines (Sotkamo, Kevitsa, Hitura and Kylylahti); however, on a global scale this production is relatively small (1,200 tonnes). New Caledonia (France) is a significant producer but its production is not accounted for by the EU. According to data available from Eurostat, the 640 tonnes per year of cobalt imported to the EU-28 come from Russia with smaller quantities from Democratic Republic of Congo, the United States and Canada and less than one tonne each from China, Turkey, Philippines, Uganda, India, South Africa and Hong Kong (Eurostat, 2016).

Lithium

Global supply of lithium has been historically dominated by hard-rock mineral sources. However, development of large-scale lithium brine operations in South America started in the early 1980's. The actual global supply market for lithium products is around 200.000 tonnes of lithium carbonate equivalent (LCE)[50], with almost 83% of it being sourced from four major producers: Albemarle (USA), SQM (Chile), FMC (USA) and Sichuan Tianqi (China) with main fields located in Chile, Australia, Argentina and China.

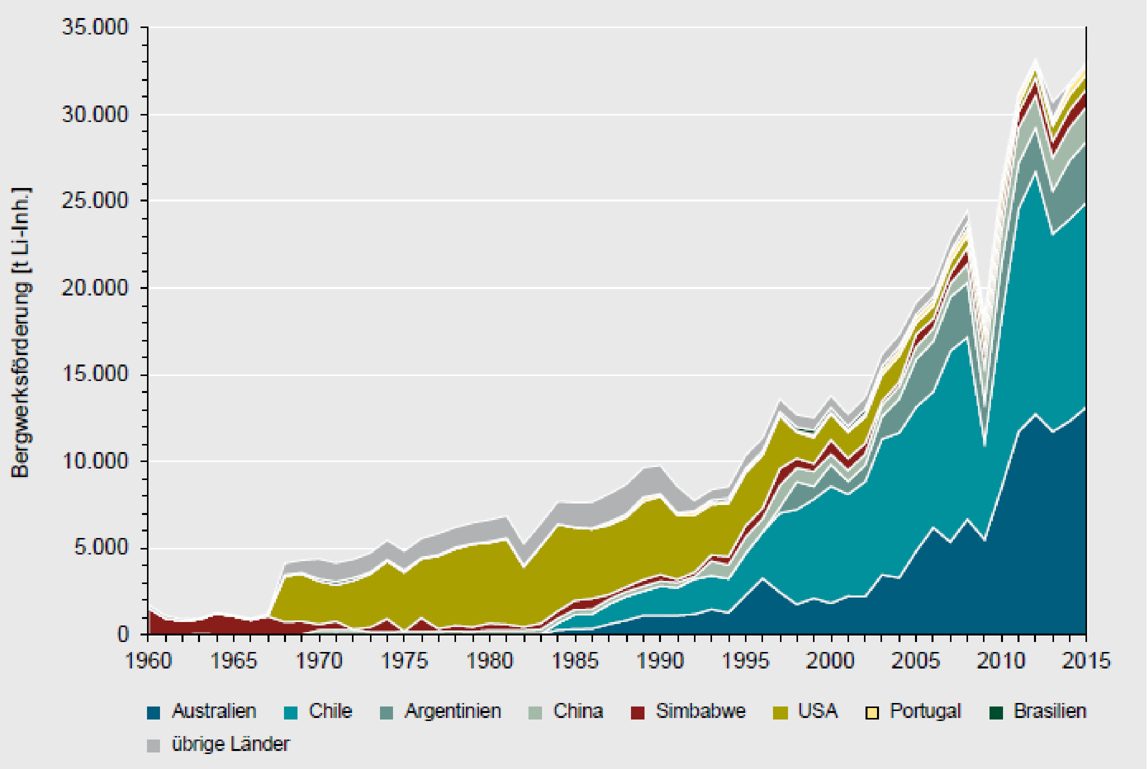


Figure 20: Global mining production of Lithium between 1960 and 2015 (DERA, BGR, Roskill).

In the EU, about 350 tonnes of lithium ores are extracted annually in Portugal from the mineral lepidolite. Spain production ended in 2011 (Bio Intelligence Service, 2015).

On average between 2010 and 2014, the EU imported about 3.600 tonnes of lithium contained in compounds.

---

[50] 1 kg lithium metal equivalent (LME) = 2.153 kg lithium dioxide (Li_2O) = 5.323 kg lithium carbonate equivalent (LCE)

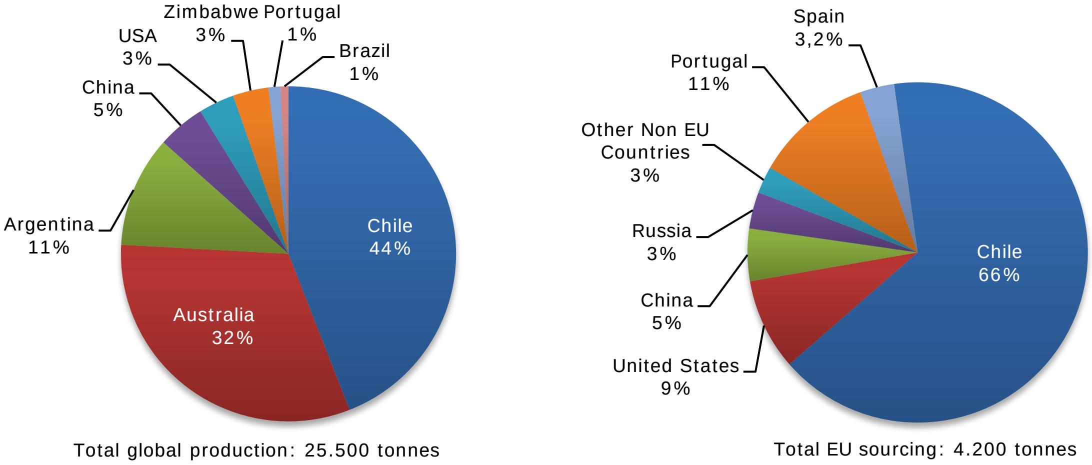


Figure 21: Global production of lithium and EU sourcing (domestic production + imports) of lithium compounds, average 2010-2014

Nickel

Most nickel mine supply growth and investment in the past five years has been in low-grade, unsuitable, nickel production, while less than 10% of nickel supply is in sulphate form (used in Li-ion cathodes), and not all is battery grade.[51] High grade nickel sulphides are found in North America, Australia, China, Russia, and Greenland.

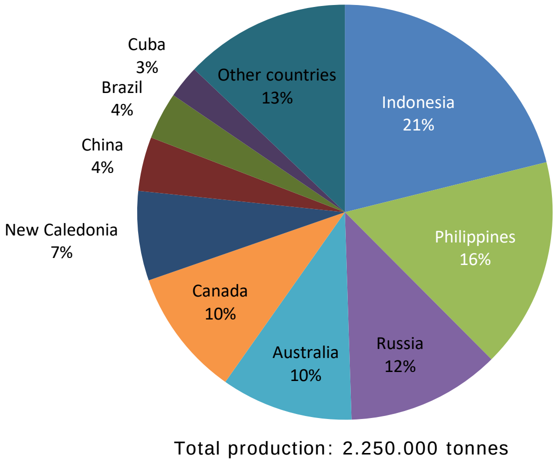


Figure 22: Global mine production of nickel ores and concentrates, average 2011–2015 (Data from World Mining Data, 2017)

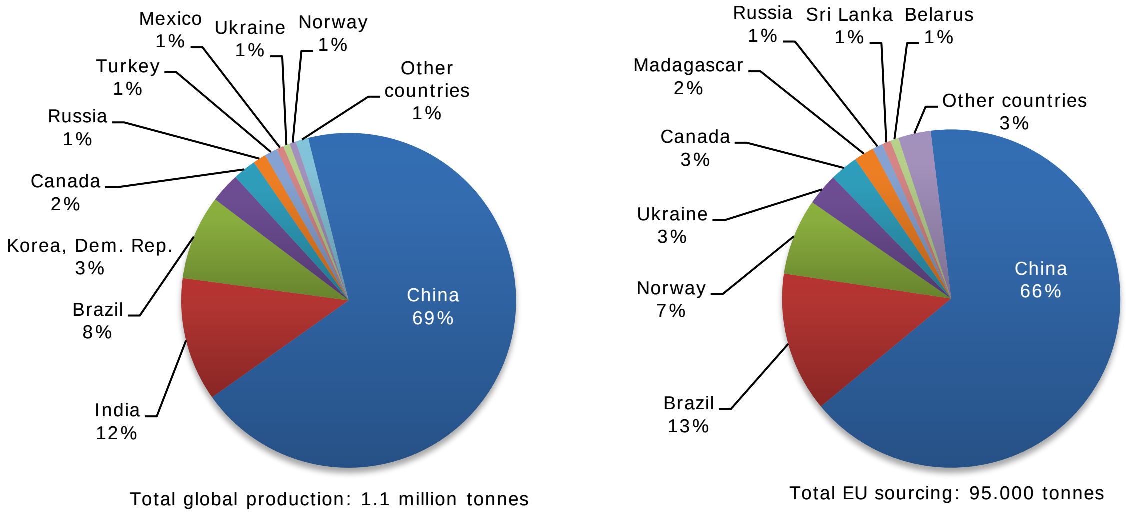
In the EU, nickel ore is mined in Finland, Greece, and on a smaller scale, in Spain. Similarly to cobalt, New Caledonia (France) is a relatively large nickel producer but its production is not accounted for by the EU.

---

[51] UBS, 2017

Natural Graphite

Annual production of graphite ore (concentrates) amounted to 1.114.894 tonnes on average during the period 2010-2014[52]. China is the world leading supplier (flake and amorphous graphite) with almost 70% (770.000 tonnes) of the global annual production, followed by India (133.258 tonnes) and Brazil (91.206 tonnes). Indian production might be closer to 25.000 t/year according to some sources (Benchmark Mineral Intelligence, 2016). Sri Lanka is a small producer (0.3% of global production) but is the only major producer of vein graphite in the world (3.000 t/year).



Total global production: 1.1 million tonnes

Total EU sourcing: 95.000 tonnes

Figure 23: Global mine production of natural graphite and EU sourcing, average 2010–2014 (Data from World Mining Data, 2016)

There is a very small production in the EU in Austria and Germany accounting for 0.05% of the global output. Sourcing of the EU practically equals the imports.

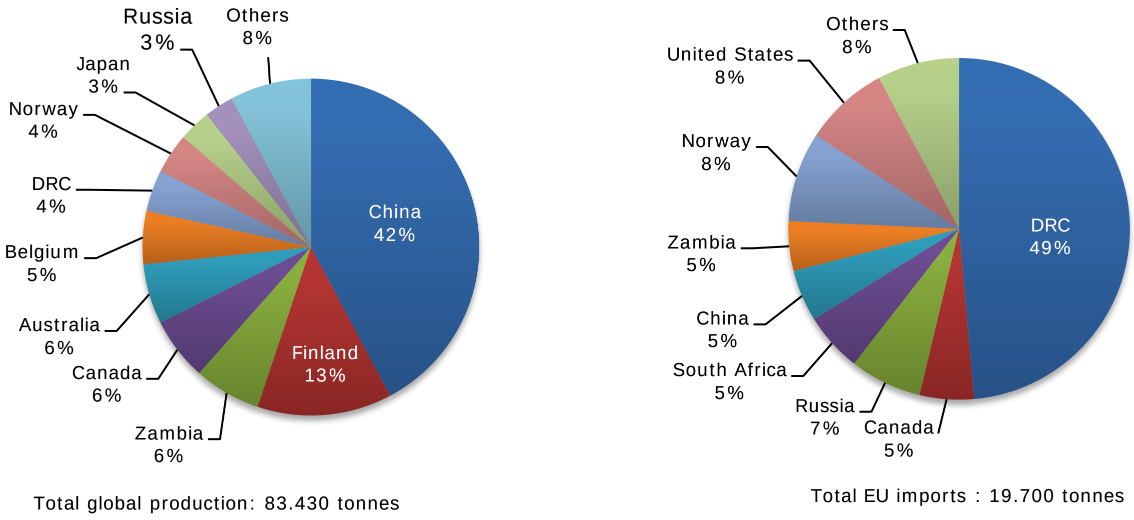
5.3. Processing and metallurgy

Cobalt

The world production of refined cobalt was about 83.400 tonnes in average over the period 2010-2014. Refined cobalt (including both metal and chemicals) is produced, from domestic and/or imported ores, in 17 countries worldwide as shown on figure 24. Other countries include (in order of production size) Brazil, Morocco, South Africa, Madagascar, India, Uganda and France.

---

[52] World Mining Data, 2016



Total global production: 83.430 tonnes

Total EU imports : 19.700 tonnes

Figure 24: Global refined cobalt production53 and EU imports54 of cobalt oxides, hydroxides, chlorides, mattes, intermediate products, unwrought metal and powders, average 2010–2014.

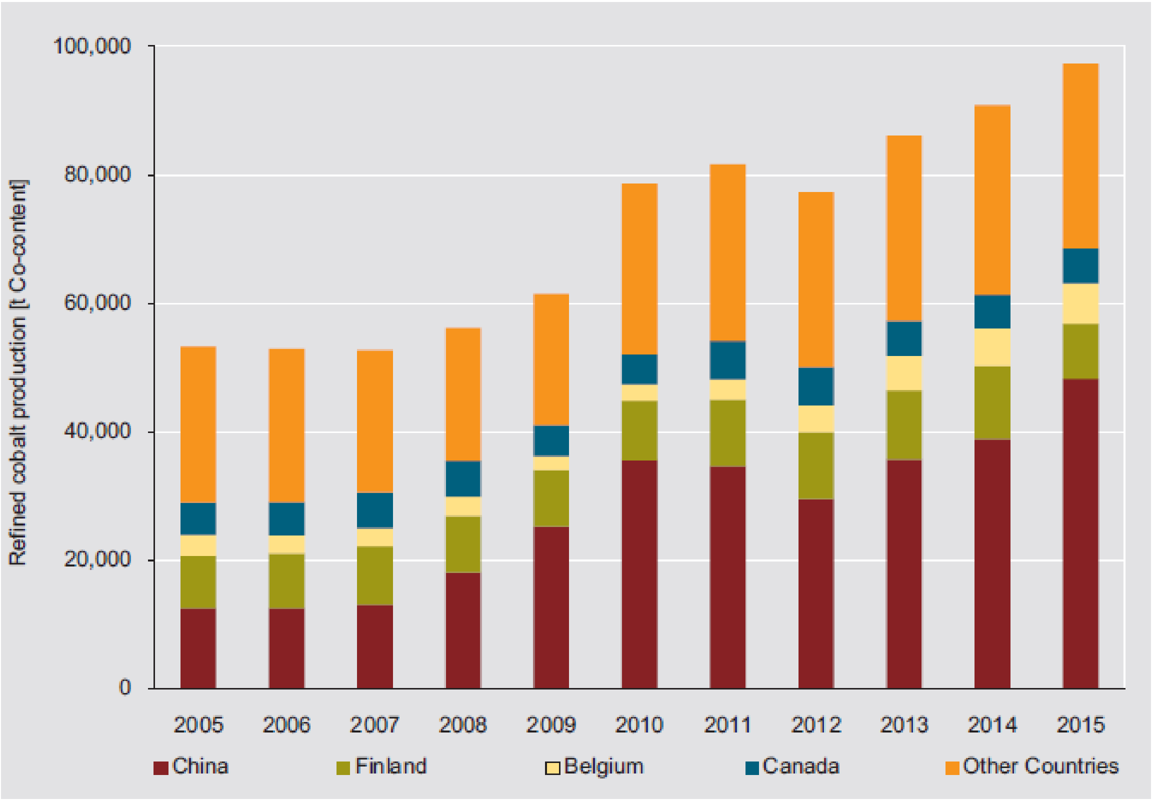


Figure 25: Refined cobalt production from 2005 to 2015 (BGR 2017, CDI 2016b).

---

[53] BGS World Mineral Statistics database - BGS, 2016

[54] Eurostat database (Comext, 2016)

Over the last decade China became a dominant producer of refined cobalt. China imports ores mainly and increasingly from DRC. This means that a smaller quantity will be available to other countries from this source.

Within the EU, refined cobalt is produced mainly by Freeport Cobalt in Finland (13% of the global production), Umicore in Belgium (5%) and Eramet in France (<1%) and small amounts also in Czech Republic, Germany, Italy, Ireland, Netherlands, Portugal, Spain and United Kingdom.

In average over the period 2010–2014, the EU-28 imported per year [55]:

- Nearly 20.000 tonnes of cobalt contained in "cobalt mattes and other intermediate products, unwrought cobalt metal and cobalt powders" to Finland (55%), Netherlands (28%) and United Kingdom (8%).
- More than 400 tonnes of cobalt contained in "oxides and hydroxides" to Spain (58%,) Italy (18%) and the Netherlands (17%).
- More than 800 tonnes of cobalt contained in "chlorides" to Denmark (99%).

These figures do not account for nickel matte imported from New Caledonia (France) to the EU-28[56]. In 2014, France imported more than 12,000 tonnes of nickel matte.

Lithium

In average, between 2010 and 2014, the EU imports of lithium compounds contained about 3.600 tonnes of lithium metal.

Some compounds are also produced in Portugal and Spain (about 600 tonnes) but they are not exported. Austria, Belgium, the Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Poland, Slovenia, Spain, Sweden and the United Kingdom are importers and exporters of lithium carbonate and lithium oxide.

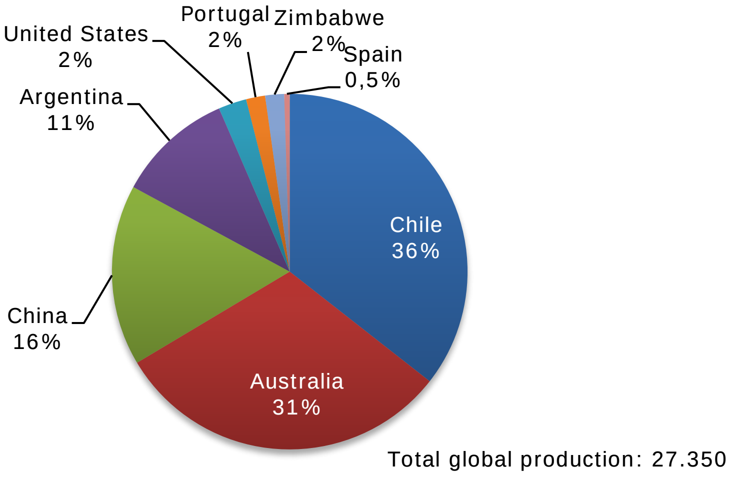


Figure 26: Global production of lithium compounds, data of year 2011 (Data from Bio Intelligence Service, 2015)

---

[55] Eurostat, 2016

[56] As explained in the mining chapter, cobalt usually is a by- or co-product of nickel mining.

Nickel

The global production of nickel metal between 2010 and 2014 was annually in average 1.75 million tonnes. China is the largest world producer of refined nickel metal, followed by Russia, Japan, Canada and Australia. Other producing countries (representing 31% of the world production) are Brazil, New Caledonia (France), Indonesia and the Philippines. Between 1994 and 2011, world production doubled from 0.9 million tonnes to almost 1.8 million tonnes. The world production remained more or less stable in recent years.

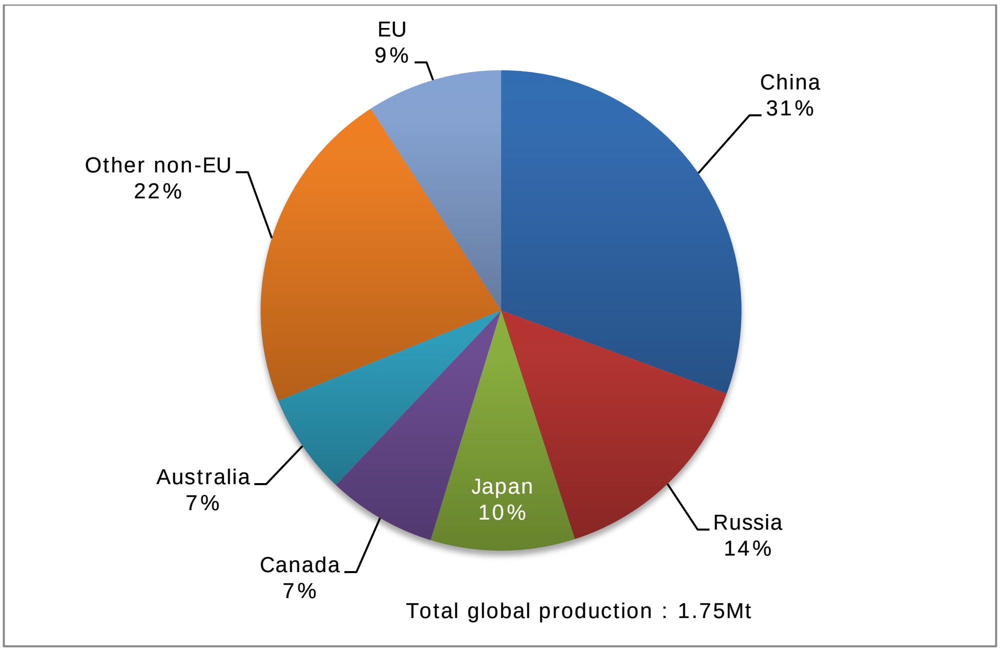


Figure 27: Global production of nickel metal, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

For the EU, nickel is smelted in New-Caledonia (France), Greece, Austria and Finland; and is refined into high purity nickel, notably in Finland, France, and the United Kingdom.

Natural graphite

China produces around 70% of the world’s graphite supply. Approximately 70% of Chinese production is fine or amorphous graphite while 30% is flake. See mining chapter for further detail.

5.4. Circular economy and recycling

A comprehensive analysis of battery raw materials and the circular economy is included in the January 2018 report on critical raw materials and the circular economy produced under the Action Plan on Circular Economy, in order to ensure a coherent and effective approach, provide key data sources, promote best practices and identify possible further actions[57].

Collection rates of waste batteries depend on the battery technology/type, on the lifetime of batteries, and on the end-use behaviour. For automotive lead-acid batteries, the collection and recycling rates are much higher than for other batteries.[58] However, significant numbers of vehicles (and embedded batteries) are deregistered in Europe and then exported as second-hand cars outside the EU, limiting the total collection volume.

Given the recent introduction of EVs on the European market, and taking into account the average lifetime of EV components (estimated to be approximately 10 years)[59], a significant number of EVs have not yet reached end-of-life. Under current circumstances of absence of substantial waste streams combined with low lithium and rare earth prices, the EU recycling infra-structure targeting EV batteries should still be adapted to the expected increase of EV batteries flows and to recover specific materials. Battery recyclers are actively preparing this future infrastructure.[60]

Material produced from battery recycling can be used for the battery industry (e.g. cobalt) or steel and other industries, depending on the quality of the recycled material.

Currently, the material of most interest to Li-ion battery recyclers is cobalt. Recycling of cobalt mainly occurs thanks to the lower costs of the recovered cobalt compared to cobalt extraction from ores. Specifically in the EV batteries sphere the recycling potential is significant as these batteries may be easier to collect if a dedicated system of return is established. Recycling of graphite, on the other hand, is quite limited. In the recycling process of batteries, graphite is usually lost in the recovery processes. Finally, the end-of-life recycling rates for lanthanum and cerium are below 1%.[61] All end-of-life recycling input rate values for these materials can be found in Table 8 in previous section of this report and simplified Sankey diagrams for two CRMs are presented in Figure 28.

---

[57] SWD(2018) 36 final. "Report on Crtical Raw Materials and the Circular Economy". See also Critical Raw Materials and the Circular Economy. Background report. JRC Science-for-Policy Report. December 2017, EUR 28832 EN, http://dx.doi.org/10.2760/378123, JRC108710

[58] IHS Consulting, 2014. "The availability of automotive lead-based batteries for recycling in the EU", available at www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final.pdf

[59] RC, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon and references therein.

[60] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, JRC Science for Policy Report, Petten, 2016

[61] EU criticality assessment, 2014. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

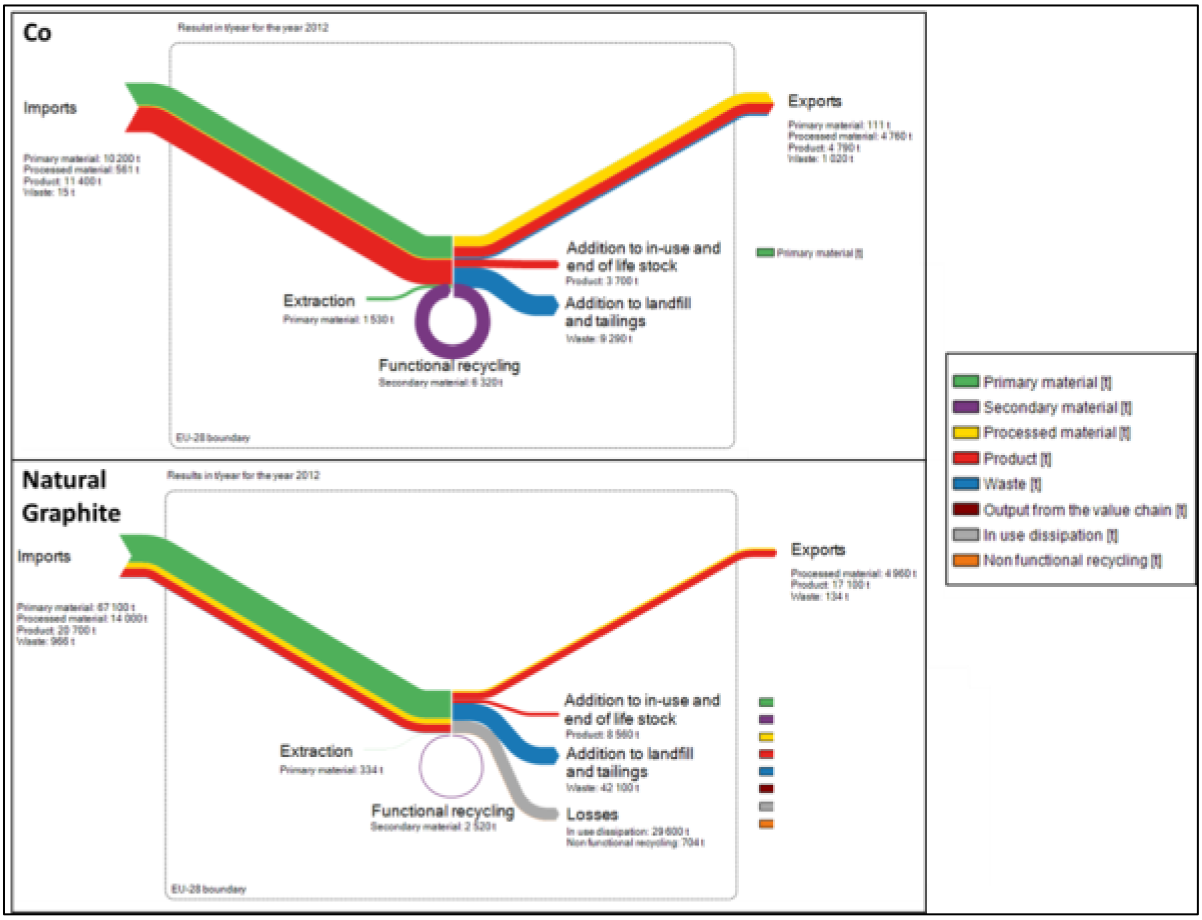


Figure 28: Simplified Sankey diagrams for cobalt and natural graphite in the EU-28 (showing the level of circularity) based on the 2015 MSA study

Among the waste batteries flows, it is worth noting that the export flow of waste batteries to non-EU Member States is low; on the contrary, there is significant movement of waste batteries and accumulators between Member States. However, batteries contained in EEE, especially rechargeable portable batteries, can enter in a second hand market outside of Europe[62]. Together with these waste flows, un-removed batteries from (W)EEE or batteries removed from WEEE but treated without recording their treatment contribute to increasing the data uncertainty[63].

The Circular Economy Action Plan, with a view to fostering increased recycling of CRMs, includes also the development of European standards for material-efficient recycling of complex end-of-life products such as batteries. A request from the Commission to the European Standardisation Organisations is underway.

Worth to mention in the context of Circular Economy and recycling, is the kick-off in May 2018 of a H2020 raw materials innovation actions named CROCODILE: *"First of a kind commercial compact system for the efficient recovery of cobalt designed with novel integrated leading technologies"*.

The CROCODILE project, with a total budget of nearly EUR 15 million, will showcase innovative metallurgical systems based on advanced pyro-, hydro-, bio-, iono- and electrometallurgy technologies

---

[62] EPBA, 2015 "The collection of waste portable batteries in Europe in view of the achievability of the collection targets set by Batteries Directive 2006/66/EC", available at http://www.epbaeurope.net/documents/Reportontheportablebatterycollectionrates-UpdateDec-15-Exerpt.pdf

[63] Ibid, EPBA, 2015

for the recovery of cobalt and the production of cobalt metal and upstream products from a wide variety of secondary and primary European resources. The new established value chain in this project will bring together for the first time major players who have the **potential of supplying 10,000 tonnes of cobalt annually in the mid-term range from European resources**, corresponding to about 65% of the current overall EU industrial demand. Therefore, the project will reduce drastically the very high supply risk of cobalt for Europe.

Large-scale recycling of EV batteries is not expected before 2020 and should only be more effective beyond 2025. Specific challenges related to the declining use of cobalt in most appropriate Li-ion chemistries may make recycling unattractive, if economic practicality is not extended to the other materials such as lithium and graphite[64]. For example, there are no obvious barriers to the recovery of graphite anode materials by hydrometallurgical and direct physical recycling processes. [65]

Certain companies have already begun investing in recycling of used EV batteries in Europe (e.g. Umicore in Belgium[66] and Recupyl in France[67]). Some (like *Société Nouvelle d'Affinage des Métaux*, SNAM, and Umicore) have teamed up with car manufacturers (such as Toyota[68] and PSA Peugeot Citroën[69] and Tesla[70]), to collect and recycle batteries.

Additionally, a number of research initiatives and pilot projects have been developed for assessing the reuse of batteries that are no more suitable for EVs in energy storage applications. Batteries2020[71], Energy Local Storage Advanced system (ELSA)[72], ABattReLife[73] and Netfficient[74] are examples of EU-funded projects looking at the most suitable and sustainable second use applications for EVs batteries. Further calls are planned[75], requiring the consideration of the whole value chain including circular economy aspects.

It is worth mentioning that there are already practical examples of Circular Economy approaches and reuse of batteries in energy storage applications such as the Amsterdam Arena[76]. The backup power will be stored in 280 batteries coming from Nissan LEAF. Extending the lifetime of batteries and of raw materials through re-use and second-use should contribute to increase the resource efficiency. Methods to assess the environmental benefits of extending the lifetime of electric vehicle batteries are under development[77,78].

---

[64] EPBA, 2015 "The collection of waste portable batteries in Europe in view of the achievability of the collection targets set by Batteries Directive 2006/66/EC", available at http://www.epbaeurope.net/documents/Reportontheportablebatterycollectionrates-UpdateDec-15-Exerpt.pdf

[65] Ibid, EPBA, 2015

[66] http://www.umicore.com/en/industries/recycling/umicore-battery-recycling/

[67] http://www.recupyl.com/104-batteries-the-future.html

[68] http://www.gov.scot/Publications/2013/12/9124/5

[69] http://www.snam.com/upload/actu/20151208%20PR%20PSA%20SNAM_A%20-%20version%20FS.pdf

[70] https://www.tesla.com/it_IT/blog/teslas-closed-loop-battery-recycling-program

[71] http://www.batteries2020.eu/

[72] http://www.elsa-h2020.eu/

[73] http://www.abattrelife.eu/

[74] http://netfficient-project.eu/

[75] https://ec.europa.eu/inea/en/horizon-2020/green-vehicles

[76] https://amsterdamsmartcity.com/circularamsterdam

[77] Ahmadi, L., Young, S.B., Fowler, M., Fraser, R.A., Achachlouei, M.A., 2017. A cascaded life cycle: reuse of electric vehicle lithium-ion battery packs in energy storage systems. International Journal of Life Cycle Assessment. 22, 111–124. doi:10.1007/s11367-015-0959-7

[78] Bobba, S., Mathieux, F., Ardente, F., Blengini, G.A., Cusenza, M.A., Podias, A., Pfrang, A., 2018. Life Cycle Assessment of repurposed electric vehicles batteries : an adapted method based on modelling of energy flows . Submitted to the Journal of Energy Storage in January 2018.

There have been a lot of industrial and research initiatives on the recycling of batteries and of their (critical) materials in recent years. Some progress has been recently achieved by the H2020 project ProSUM. Its Urban mine platform captures batteries stocks and flows including data on batteries put on the market, compositions, lifetimes and collections rates[79].

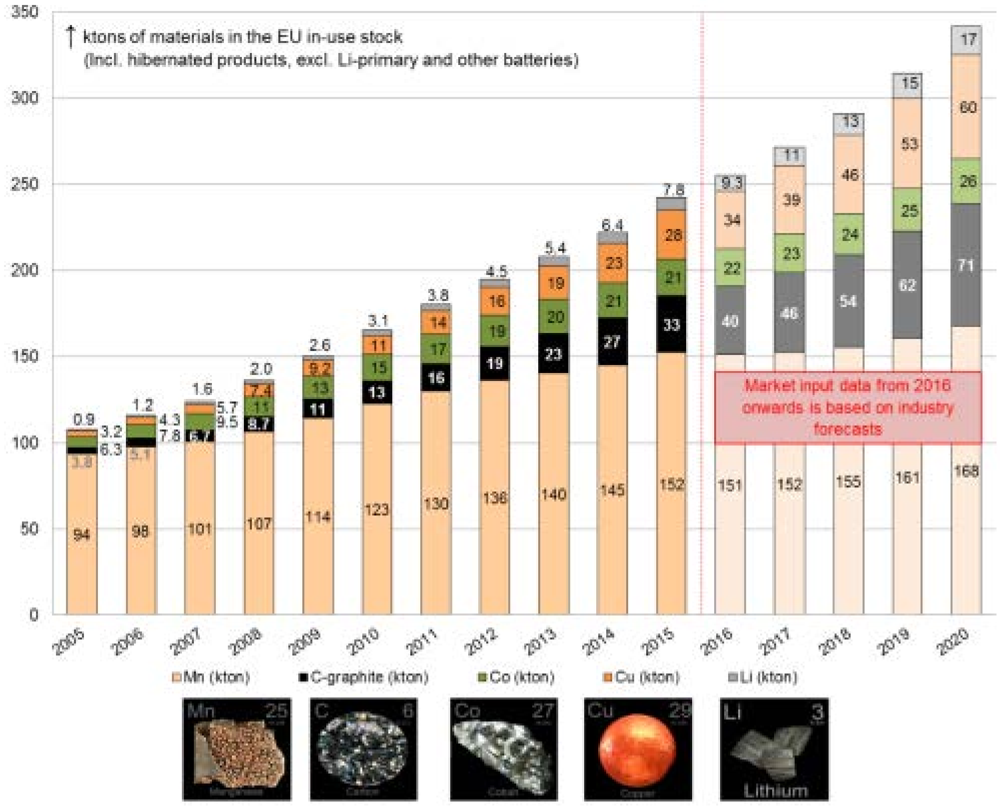


Figure 29. The EU Urban mine development from 2005 to 2020 for selected elements in batteries[80]

Figure 29 presents, for example, that the total stock of secondary lithium and natural graphite grows with roughly 500% from 2010 to 2020 and cobalt with roughly 200%. At the same time for lithium, the growing stock in 2016 is about 4 times the estimated total annual EU consumption of the metal in batteries. This illustrates the potential significance of future recycling of the urban mine provided that economic incentives, collection amounts, recovery technologies and, ultimately, recycling rates improve.

Further work will be needed in this area to better understand the significant flows of batteries of unknown whereabouts, capture forecasts, evolution of compositions and actual recycling rates for the most relevant materials, so that future availability of secondary raw materials from batteries as an alternative source of materials is better understood and reported.

---

[79] http://www.urbanmineplatform.eu/

[80] http://www.urbanmineplatform.eu/homepage [accessed on 5/4/2018]

6. POLICY AND REGULATORY FRAMEWORK[81]

The Treaty on the Functioning of the European Union (TFEU) defines the general framework for the functioning of the EU. It set ups exclusive competences of the EU on competition rules or international agreements and shared competences on environment, nature protection or health and safety that are relevant for the non-energy extractive industries (NEEI).

Raw materials are mentioned in the TFEU indirectly, emphasising the principle of prudent and rational use of natural resources (art. 191(1)) but does not consider the importance of domestic primary raw materials in the security of supply or the integration of raw materials in land use planning. Therefore, EU Internal Market, Environmental, Nature Conservation, Water, Emissions, Chemical Safety, Extractive Waste or Occupational Health & Safety Directives are applicable to the non-energy extractive sector while Mineral resource management, permitting and mining legislation are in full competence of the Member States

6.1. Raw materials policy

The EU raw materials strategy[82] aims at securing access to raw materials for the EU economy. The policy was reinforced in 2012 with the launch of the European Innovation partnership on raw materials. This strategy is based on (1) sustainable sourcing of raw materials from global markets, (2) sustainable domestic raw materials production, and (3) on resource efficiency and supply of secondary raw materials. In September 2017, the Commission adopted a renewed EU industrial policy strategy[83] which highlighted the importance of raw materials, particularly critical raw materials (CRMs), for the competitiveness of all industrial value chains, for the EU economy.

A well-established raw materials policy has shown to be crucial in mineral safeguarding. It sets the general priorities in raw materials resources management and contributes to the secure supply to downstream users. Based on the EU Raw Materials Initiative, several of the EU Member States and regions updated their raw materials policies/strategies. Due to different geological settings, they cover different types of minerals and favour different sourcing options, including mining, recycling, resource efficiency or external supply. In the area of resource efficiency and recycling the most important and relevant piece of EU legislation is the Batteries Directive.

---

[81] MIN-LEX,2017, https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

[82] The Raw Materials Initiative: COM/2008/0699

[83] A Renewed Industrial Policy Strategy: Communication "Investing in a smart, innovative and sustainable industry", COM(2017) 479

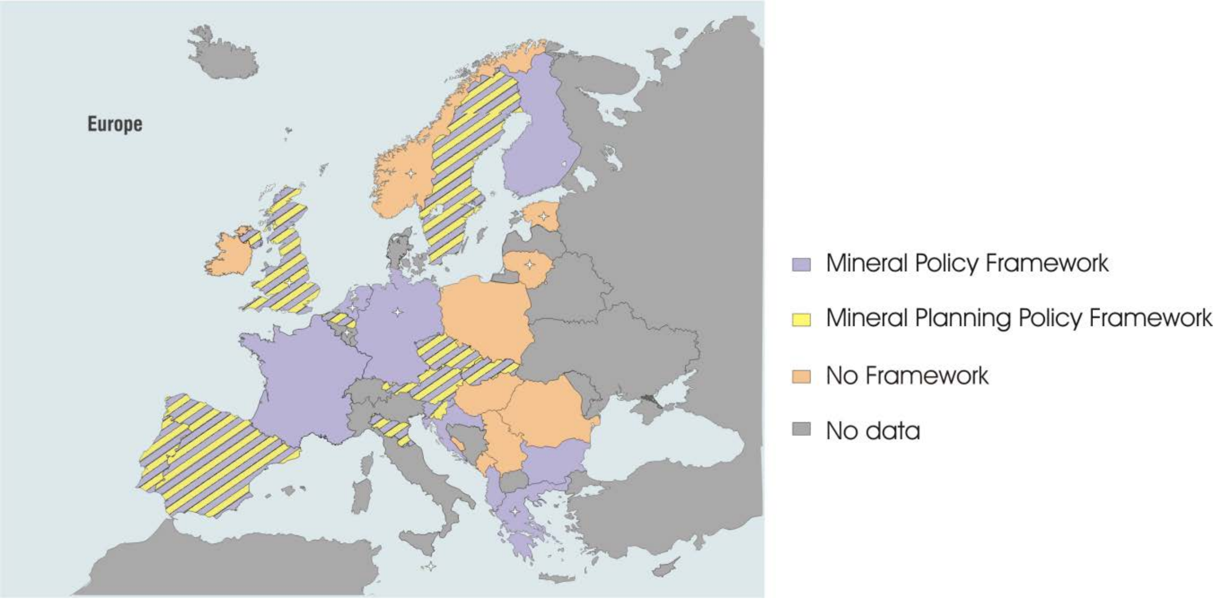


Figure 29: Raw materials policy and mineral planning policy frameworks in Europe (Minatura2020)

Table 9: Overview of the EU Member States' raw materials policies, battery raw materials potential, and battery production

Country	**Raw materials policy/Strategy**[84]	**Raw materials production (*Potential*)**[85]	**Battery production**
Austria	The Austrian Minerals Strategy (2015)	Natural graphite, nickel (*Cobalt, lithium*)	Operational
	Mineral Resources Plan (2012)		
Belgium	Federal- offshore: Marine Spatial Plan of the North Sea and Royal Decree of 20 March 2014		
	Flanders: Decree on Surface Mineral Resources (2003); VLAREOP (2004) – Order of the Government of Flanders on rules for the implementation of the Surface Mineral Resources Decree.´		

---

[84] https://www.min-guide.eu/

[85] EU critical raw materials assessment 2017, Minerals4EU

	Flanders: Materials Decree (2011) - Decree on the sustainable management of material cycles and waste; VLAREMA (2012) - Order of the Government of Flanders adopting the Flemish regulation on the sustainable management of material cycles and waste		
Bulgaria			
Croatia			
Cyprus			
Czech Republic	The Raw Material Policy of the Czech Republic in the Field of Mineral Materials and Their Resources (1999)	- (*Lithium, natural graphite*)	
Denmark	Denmark, Greenland and the Faroe Islands: Kingdom of Denmark, Strategy for the Arctic 2011– 2020		
	Regional Mineral and Raw Material Resources plans		
Estonia	National Development Plan for the Use of Construction Minerals 2011–2020		
Finland	“Finland’s Mineral Strategy” (2010) “Making Finland a leader in sustainable extractive industry – action plan” (2013)	Cobalt, nickel (*Lithium*)	
France	“National strategy for the sustainable management of terrestrial and marine aggregates and of quarried materials and sub-stances” (2012)	Cobalt, nickel (*Lithium*)	
	“The strategic metals” Plan of Action (2010)		
Germany	The German Government's raw materials strategy (2010)	Natural graphite (*Cobalt*)	Operational
	Raw materials of strategic economic im-portance for high-tech made in Germany published by the Federal Ministry of Education & Research (2013)		
	German Climate Action Plan (CAP) 2050 (2016)		
Greece	National Policy for the Exploitation of Mineral Resources (2012)	Nickel	
	Greek extractive industry international environment profile. Prospects		
Hungary			Planned or under construction
Italy	Emilia-Romagna region		
Ireland		- (*Lithium*)	
Lithuania			
Latvia			
Luxembourg			
Malta			
Netherlands	Title:“ Policy Document on raw materials“ Published by the Dutch Government (2012)		

	“A Circular Economy in the Netherlands by 2050. Government-wide Programme for a Circular Economy” Published by the Dutch Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs (2016)		
Poland	in preparation	Nickel (*Cobalt*)	Planned or under construction
Portugal	"National Strategy for Geological Resources - Mineral Resources” (2012) “Strategy for the lithium resources in Portugal 2018 – Resolution from the Council of Ministers no 11/2018”[86]	Lithium (*Cobalt, nickel*)	
Romania	Mineral industry Strategy 2012–2035		
Slovenia	National mining stategy (2009)		
	National Mineral Resource Management Programme		
Slovakia	Raw materials policy (2004), to be updated	- (*Cobalt, lithium, natural graphite*)	
Spain	Andalucía Region. Mining Strategy 2020 Castilla y León Region. Mineral Resources Strategy 2017-2020 Castilla la Mancha Region. Strategic Plan for non-energy mineral resources 2020	Lithium, nickel (cobalt)	
Sweden	Sweden’s Minerals Strategy“ (2012/13)	- (*Cobalt, lithium, nickel, natural graphite*)	Planned or under construction
United Kingdom		Nickel	Operational

6.2. Batteries Directive

The Batteries Directive (2006/66/EC) establishes obligations for Member States and industrial operators to maximise the collection of waste batteries and accumulators, and to ensure that all collected batteries undergo proper treatment and recycling. The Directive also aims to achieve a high level of recycling for all waste batteries. To this end, the Directive defines targets for collection rates and for recycling efficiencies.

According to the data submitted to the Commission, fifteen Member States[87] are considered to have met the established target (45%) for the collection of waste portable batteries.[88] For automotive lead-acid batteries, the collection and recycling rates are much higher than for other types of batteries.[89]

However, recycling processes in most countries achieved the minimum levels of recycling efficiencies set by the Directive for lead, nickel-cadmium and other types of batteries. Within the EU, therefore, the problem to ensure an appropriate recycling seems to relate more to logistic process associated with the collection of waste batteries than with the efficiency of recycling in itself.

---

[86] https://dre.pt/home/-/dre/114610495/details/maximized

[87] Austria, Belgium, Bulgaria, Croatia, Denmark, France, Finland, Germany, Hungary, Ireland, Lithuania, Luxembourg, Slovakia, Sweden and United Kingdom.

[88] http://ec.europa.eu/eurostat/web/waste/data/database

[89] IHS Consulting, 2014. “The availability of automotive lead-based batteries for recycling in the EU”, available at www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final.pdf

The Directive requires the Commission to review the impact of its provisions on the environment and internal market as well as to evaluate some particular aspects, in relation to e.g. heavy metals, targets and recycling requirements. The Commission launched in 2016 an evaluation process intended to assess whether the Directive is delivering its objectives, considering also whether new uses of batteries and the new technologies and chemistries developed since its adoption in 2006 are duly addressed. Likewise, the coherence between the provision of the Directive and EU policies on Circular Economy and raw materials will be assessed. If necessary, proposals for revision of the related provisions of the Directive will be prepared.

6.3. Legislative framework

Most of the Member States regulate mining through a main mining act. The mining act usually determines the mineral ownership and permitting provisions related to exploration, extraction and post-extraction (land rehabilitation) of minerals.

Mineral ownership is an important aspect for permitting because in many Member States permitting procedures differ for state-owned/state-controlled minerals (usually encompassing high value minerals) and for land owned minerals (usually encompassing low value, bulk minerals).

Mining act is usually complemented by other acts and different types of legal instruments regulating multiple issues related to the environmental and socio-economic aspects of the NEEI sector. Mining and environmental legislation represents largest proportion of permitting related laws in Member States.

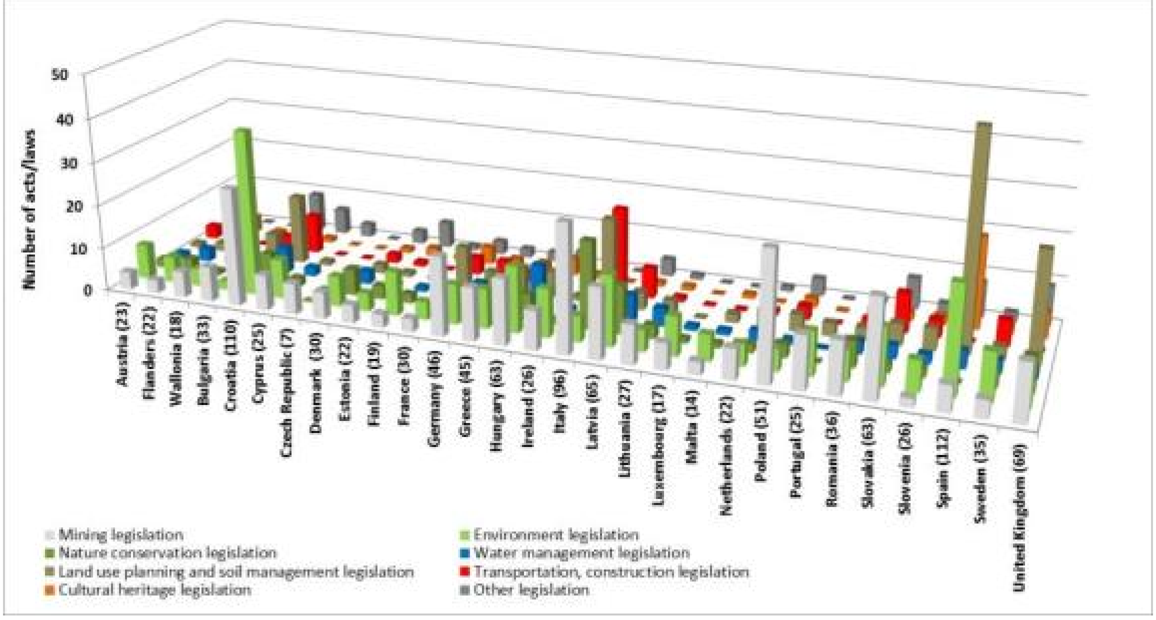


Figure 30: Total number of laws per MS relevant for NEEI permitting procedures. Note: Germany has a decentralised system, and total number of laws only represents the example of Mecklenburg-Western Pomerania. The UK includes laws for England, Wales and Northern Ireland. (MINLEX study [90])

---

[90] MINLEX, 2017 : https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

The Environmental Impact Assessment (EIA) Directive applies to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment. In line with the rules established by the Treaty on the Functioning of the European Union, some Member States are entitled to go beyond the minimum requirements of EU environmental legislation and apply higher environmental requirements than those stipulated e.g. in the EIA Directive. These differences in transposition may however result in a higher administrative burden for industry.

The Nature Directives are largely coherent internally and with each other and provide opportunities for adequate implementation via close cooperation between different stakeholders ensuring streamlined permitting procedures in relation with mineral resource sites overlapping Natura 2000 areas.

The Extractive Waste Directive is an item of the EU secondary legislation which is directly dedicated to the NEEI sector. There also are some differences in its implementation across the EU, e.g. in terms of use of inert waste lists.

6.3.1. Land use planning

Access to mineral deposits and permitting is very dependent on the land use planning. Most of the EU Member States have a specific land use planning policy. However, consideration of minerals in the land use planning, type and details of data are heterogeneous. Austria, Czech Republic, Poland, Slovakia, Slovenia and Sweden protect certain minerals by legislation. Only Flanders (BE) and the Netherlands consider 3D spatial planning.

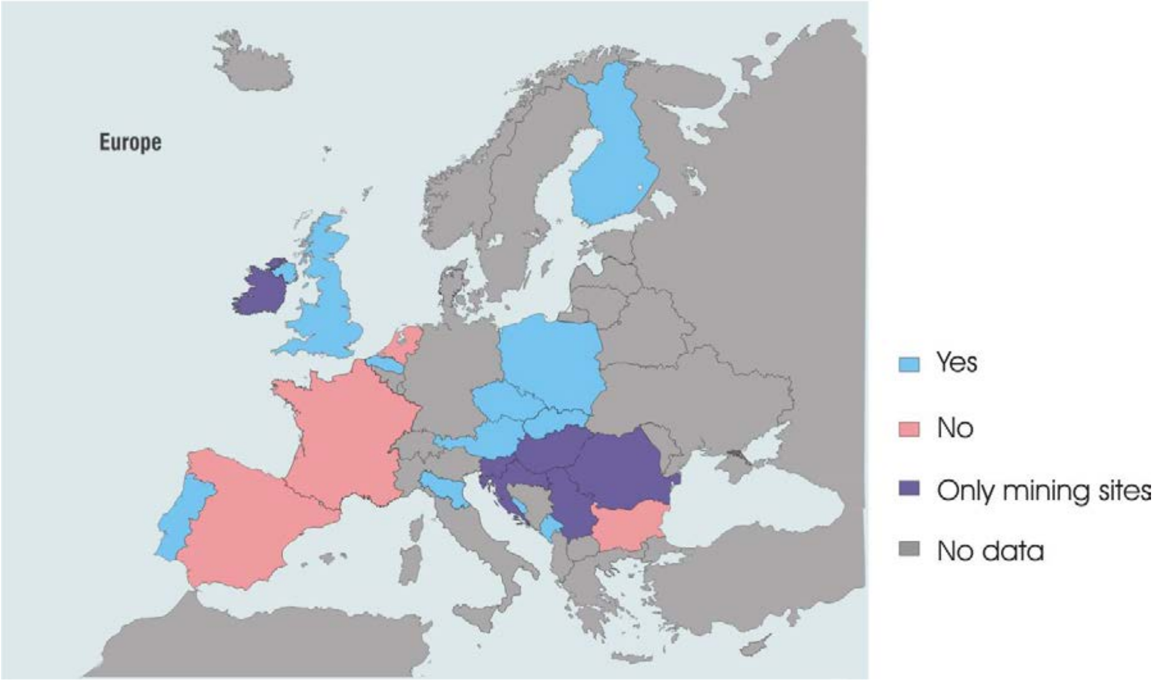


Figure 31: Land use planning policies covering mineral deposits in Europe (Minatura2020)

6.3.2. Financial aspects

Financial incentives and taxation of mining are an important factor in attracting investment and engagement with local communities and local authorities. Taxation and royalties include, inter alia, corporate tax, royalty, land use tax, environmental tax, concession fees, exploration and extraction permitting fees, financial guarantees.

The overall analysis in Member States shows heterogeneity as a result of differences in national mining legislation systems or mineral ownership.

According to MINLEX study[91], Portugal, as an example, introduced changes to the royalties system to ensure that part of the income generated benefits the local communities in areas where mining activity takes place. Up to 25% of royalties payable as part of all concession agreements for exploration or exploitation can be allocated to finance sustainable development projects. The measure simplifies the royalty's regime and ensures that the local communities get additional benefits through social, economic or environmental support projects in their area. In parallel, it helps the mining industry improve its public profile and strengthen the ties with the local communities.

Financial incentives may energize mining investments to provide comparative preference to certain forms of activities and selected regions for mining. Finland and Spain have been identified in MINLEX study as examples with regards to positive state intervention to promote exploration and extraction.

6.4. Permitting in Member States

Fast, clear and predictable permitting process combined with a robust EIA are crucial to promote a good business climate and investment certainty for a company to open or extend a mine (for battery raw materials). It is also acknowledged that the EIA should be proportionate and executed in a timely and efficient manner.

The competent authorities involved in permitting are not only mining authorities but also environment, land use, health and safety, nature conservation, or water management authorities. These authorities are entitled to make legally binding decisions and/or that act as consulting voices in the process.

However, according to the MINLEX study[92], complexity and efficiency of the permitting processes, particularly for mining metallic ores, has become a topic of concern in the last decades. This is attributed to increasing permitting times, low predictability of the decisions and public acceptance influencing the decisions.

Currently, the authorisation process is complex and slow in some countries, taking typically five to ten years to obtain authorisation for a new production site.

It was concluded from the study that complex permitting procedures with unexpected delays influence a mining project´s value and increase the financial risk of a mining investment. Inadequate permitting procedures create a higher risk of allowing mining projects to proceed without appropriate and effective requirements for environmental protection and mine reclamation.

6.4.1. Competent entities in permitting

Across all MSs the permitting procedure for the NEEI revolves around a principal national or regional authority who issues an exploration or an extraction permit and co-authorities at all levels (e.g. environmental permits such as the approval of an EIA study or water management permits, etc.) or their consent. How national and regional authorities interrelate with each other is defined by the legal framework. In the EU three different permitting regimes type can be identified.

---

[91] MINLEX, 2017 : https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

[92] MINLEX, 2017 : https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

- Centralised regimes. The exploration or extraction permit is granted by a national authority. Also often environmental and other necessary permits/licences by co-authorities are mainly granted at the national (or federal) level.

- Decentralised regimes. The permits or licences are granted mainly by regional (provincial) or municipal authorities, in countries where permitting powers have been devolved from national to subnational jurisdictions.

- Mixed ones are regimes where there is a combination of national and regional authorities and whereby competences may vary according to the mineral type or the mineral development phase (exploration or extraction).

In Table 10, the permitting of onshore non-energy minerals is slightly dominated by mixed regimes (12), followed by centralised ones (11) with only five MSs having decentralised regimes. For offshore minerals, there is a clear predominance of centralised regimes (21), with only Germany having reported a decentralised (regional) permitting scheme.

Table 10: Classification of Member States per permitting regime type.

	Centralised	Decentralised	Mixed
Onshore	10 (BG, HR, CY, EE, LV, LT, MT, NL, RO, SI)	6 (Flanders, DK, DE, IT, ES, UK)	12 (AT, Wallonia, CZ, FI, FR, HU EL, IE, PL, PT, SK, SE)
Offshore	21 (BE, BG, HR, CY, DK, EE, FI, FR, EL, IE, IT, LV, LT, MT, NL, PL, PT, RO, SI, SE, UK)	1 (DE)	0

The number of authorities (mining, environmental, land use) and the number of permits needed to grant permission for activities to begin is smaller for exploration than for extraction: without distinguishing per type of mineral, an average of 3.03 authorities are involved in the permitting for onshore exploration and 4.02 for onshore extraction.

Only 9 jurisdictions have one-stop shops – even though the concept of one-stop shop has been promoted for years as “good practice” for making permitting procedures in the NEEI sector more efficient.

6.4.2. Permitting and real time frames

The average length to obtain a mining permit varies among Member States and depends on the mineral and the project´s size, location and complexity; e.g. if a project is large and complex, a longer permitting time is often needed due to environmental studies.

Exploration permits

The procedure to obtain an exploration permit in Europe begins with a request to the mining authorities indicating the substance, the area requested, and exploration works to be implemented. In many cases, exploration permits are not required. When permits are required, in many cases (AT, BE, IE, IT, LV, LU, ES, PT, UK) no Environmental Impact Assessment (EIA) is required. However, other Member States may require an environmental permit for exploration (e.g. DK, EE, FI, HU, LT, PL, RO, SK).

Overall, exploration in Europe is not excessively complicated and there are no significant bottlenecks.

Extraction permits

Most MSs have a procedure which is dependent on the application to the permit by the interested party (DK, EE, FI, FR, DE, EL, HU, IE, IT, LT, PL, PT and ES). All EU MSs require EIAs and subsequent environmental evaluation and authorisation previous to the grant of an exploitation concession.

Largest delays are reported for metals mining projects. Delays in extraction permits are caused in some Member States by delays in the granting of environmental permits (both permits being closely interrelated). Additionally, appeals to permits granted by authorities can also considerably prolong the time for permitting procedures.

Good practice

A “one-stop shop” concept for NEEI permitting procedures is being advocated since long and some jurisdictions have such regime in place. Such regimes are needed as they facilitate an efficient and optimal coordination among authorities, which is necessary when dealing with inter-disciplinary complex NEEI projects.

Appropriate integration of land use planning and permitting procedures has the potential to facilitate permitting procedures, avoid appeals, increase permitting success rates and confer investment security to prospective investors. Given that many of the mining areas in the EU (as shown in figure 17) are relatively close to a national border, potential impacts of mining on cross-border regions should also be assessed in the permitting process. One of the most effective ways to streamline permitting procedures is to engage in early and meaningful consultation procedures with the authorities and the public on the basis of high quality environmental studies and guidance documents (e.g. EC´s Non-energy mineral extraction & Natura 2000 guidance).

7. MAIN ISSUES TO BE CONSIDERED

The chapter highlights the main issues to be considered in line with the Strategic Action Plan for Batteries which includes targeted measures at EU level including in raw materials (primary and secondary), research and innovation, financing/investment, standardisation/regulatory, trade and skills development, in order to make Europe a global leader in sustainable battery production and use.

7.1. Improving knowledge on battery raw materials

The first major issue is the availability of reliable information necessary for making informed decisions about the supply of raw materials for the battery value chains in the EU. Most of the relevant knowledge regarding minor metals, as cobalt or lithium, is either unavailable, scattered, confidential or of low quality, many times based on “expert judgement”. Data in the EU is reported under different standards, which makes their comparison and integration difficult, while there is a universally acceptable and internationally applicable scheme for the classification and reporting of all energy and mineral resources – The United Nations Framework Classification for Resources (UNFC).

7.2. Boosting primary and secondary battery materials production in the EU

Several factors influence industry decisions regarding location of the battery production facilities, incl. policy, regulatory and business environment, access to raw materials, proximity to customers, access to skilled workforce, R&D capacity and IPR protection.

The EU is sourcing primary raw materials supply mostly from third countries. Usually, the global market of these materials is concentrated and vulnerable to supply disruptions. For example[93], globally DRC (64% of 135,500 tonnes) is biggest producer of cobalt ore and China (42% of 83,430 tonnes) is the biggest producer of refined cobalt. Another example is lithium, almost 83% of the actual global supply of lithium is being sourced from four major producers: Albemarle (USA), SQM (Chile), FMC (USA) and Sichuan Tianqi (China) with main fields located in Chile, Australia, Argentina and China, while there is no similar global level producer based in the EU.

The EU’s domestic supply of battery raw materials is currently very limited despite a good mineral potential in the EU. Mining is a competence of Member States. Main obstacles to using the EU potential include lacking geological data necessary to discover deeper deposits; difficult access to known deposits, mainly due to weak integration of land use planning and mining; diverse regulatory conditions across the EU and low public awareness of raw materials and acceptance of production operations[94]. Clear and predictable permitting process is crucial for an investment decision of industry to open or extend production of battery raw materials.

Similarly, recycling of the battery materials still has not reached its full potential in Europe. Nickel is recycled largely and currently covers around 34% of the EU consumption. Global end-of-life recycling rate for cobalt is also high 68%[95], but covers only minor part of the growing demand. Today the recovery of lithium and graphite from batteries is technically feasible, but is still not economically viable.

---

[93] Average of period 2010-2014, Criticality assessment 2017

[94] Raw Materials Scoreboard: https://publications.europa.eu/en/publication-detail/-/publication/1ee65e21-9ac4-11e6-868c-01aa75ed71a1/language-en

[95] UNEP, Recycling rate of metals, 2011 http://www.unep.org/resourcepanel/portals/24102/pdfs/metals_recycling_rates_110412-1.pdf

Substitution of critical raw materials by non-critical raw materials and better resource efficiency can also contribute to the circular economy by reducing the pressure on the raw materials demand and supply. The material-for-material substitution for nickel and cobalt in battery applications is limited. For lithium and graphite substitution is possible, but at higher price.

7.3. Ensuring access to battery raw materials on global markets

The main global producers and suppliers of some critical battery raw materials to the EU are highly concentrated in several third countries. It could be useful to use all appropriate policy instruments such as diplomacy and trade to ensure sustainable and fair access to raw materials for batteries in third countries and promote socially responsible mining.

8. BIBLIOGRAPHY

Bio by Deloitte. (2015). Study on Data for a Raw Material System Analysis. Background data (unpublished)

BGS (2016). World Mineral Production 2010-2014. Keyworth, Nottingham British Geological Survey. Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Cobalt Development Institute. (2016) Cobalt Supply and Demand 2016.

EU Criticality assessments and Critical Raw Materials lists 2011, 2014 and 2017.. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat. (2016) International trade in goods database (COMEXT). Available at: http://ec.europa.eu/eurostat/data/database

Minerals4EU (2015) European Mineral Yearbook – Data for cobalt. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Minlex, 2017: EU MINLEX study. Available at https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

MSA, 2015. Study on Data for a Raw Material System Analysis: available at https://publications.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1/language-en , doi:10.2873/876644.

USGS. (2016). Cobalt Mineral Commodity Summary: Available at: http://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2016-cobal.pdf

United Nations. (2016) Commodity Trade Database. Available at: https://comtrade.un.org/

United Nations Environment Programme. (2011) Recycling Rates of Metals A Status Report, p.44. Available at: http://www.unep.org/resourcepanel/Portals/50244/publications/UNEP_report2_Recycling_130920.pdf