II / 2023 ▪ Analysis

# Resilient Supply Chains in the Battery Industry

Publication of the accompanying research on battery cell production on behalf of the German Federal Ministry for Economic Affairs and Climate Action

in cooperation with

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BATTERY CELL PRODUCTION

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# 1 EXECUTIVE SUMMARY

The transformation of the automobile industry in Germany is essential in order to achieve the climate policy objectives of the coalition agreement. 15 million fully electric passenger vehicles by 2030 is the established goal. This transformation process needs to be highly dynamic if the development into Europe's leading market for electromobility is to be realised.

To support the establishment of a sustainable and competitive battery value chain, the European Battery Alliance (EBA) was founded. Additionally, two Important Projects of Common European Interest (IPCEIs) were approved by the European Commission in 2019/2020 to realise the goal of high-capacity European battery production by 2030. Provided that all of the battery cell projects that have been announced are implemented, most of the European automobile industry's demand could be covered in Europe by the year 2030.

A large proportion of value creation and the performance of an electric vehicle are tied to the battery. However, Europe is highly dependent on battery cell imports today.

None of the raw materials required for battery cell manufacturing are currently mined in significant quantities in Europe. Europe is therefore highly dependent on the import of mineral raw materials. The global dynamics in the development of cell manufacturing capacities will lead to new or worsening dependencies and shortages, especially regarding the supply of materials. In addition, Europe lacks sufficient capacities for further processing.

Notwithstanding the increase in recycling and European raw material projects that have been announced, this import dependency will remain largely unchanged by 2030 according to numerous experts. For example, 100% of the lithium for battery applications is imported today. Even if Europe realises the raw material and refining projects that have been announced to date, Europe would only be able to mine about 25% of its own lithium demand and refine about 50% of the needed intermediate lithium products in 2030. The situation is similar for the supply of nickel, manganese, cobalt and graphite for battery cell manufacturing. A European self-sufficiency with raw materials will not be possible.

Europe remains dependent on international cooperation to secure the supply of metals for batteries. Against the background of rising international tensions, resilient supply chains are thus becoming more important. It is therefore tremendously important for companies in the European battery ecosystem to diversify their supply chains. Influence on the supply chain can be increased through partnerships and direct investments. Geopolitical risks also have to be re-evaluated. With the Critical Raw Materials Act, the European Commission is accounting for geopolitical changes and the re-evaluation of raw materials policy.

Only the recycling economy will offer a way out of the raw material dependency in the long term. However, the cycle has to be filled with raw materials before the transition to a circular economy can succeed.

# 2 BATTERY CELL MANUFACTURING SUPPLY CHAINS

Worldwide exports of goods accounted for more than one-fifth of the global gross domestic product (GDP) in 2020.[1] This enormous magnitude of international trade is a key characteristic of globalisation and, among other things, requires closely meshed supply chains spanning the globe. Thanks to today's global networking, production processes can be broken down and located in any region around the world. Economic benefits arising from cost differences, the availability of production factors and a favourable investment climate can thus be realised.

The current disruptions of production processes and commodity flows due to the COVID-19 pandemic as well as geopolitical conflicts illustrate how drastic the risks are for a complex supply chain which is based on a demand-synchronised production. Companies are often able to respond in the short and medium term to alleviate the consequences of supply bottlenecks and implement safeguards, such as obtaining insurance, increasing inventory levels or concluding contracts with emergency suppliers. However, long-term risk minimisation by adapting the supply chain strategy is generally associated with higher costs for companies. Since the global division of labour along the value creation stages has become tremendously geographically concentrated the reduction of risk reduction is to some extent hardly possible. With regard to the battery cell manufacturing value chain, many steps such as the recycling of certain raw materials or cathode and anode production are highly concentrated in China.

A high concentration is in part found at the company level as well. The number of existing suppliers for some goods is small.[2] These oligopolies can become a potential problem, especially when the goods in demand cannot be substituted at a reasonable cost. As a result, options for the diversification of procurement are in part very limited, meaning that companies on the demand side have few options for reducing their dependency. In the context of battery cell manufacturing, this applies to certain raw materials, such as primary lithium extraction, cobalt, nickel and battery graphite.

However, the free trade has been showing signs of weakness for some time. International trade has only grown slowly since the 2008/2009 financial crisis and more governments critical of globalisation have come to power.[3] Furthermore, the World Trade Organisation (WTO) in its role as the organiser of world trade has been weakened by numerous internal and external conflicts (see INFOBOX: Goals of the World Trade Organisation).[4] Conflicts are therefore more likely to interfere with international trade relations. It appears that the era of trade that is largely detached from political influence, which follows defined rules and optimises supply chains according to capitalist logic, is drawing to a close for the time being. A shift from a rule-based system with equal rights to a power-based trade regime is looming. This development generates new risks for international trade and increases the need for more resilient supply chains. The mentioned trend is expected to result in greater political intervention in trade matters.

**Goals of the World Trade Organisation:**

Liberalisation of the markets, the lowering of duties and the creation of a world trade order. Since August 2016, the WTO has 164 members accounting for about 98 per cent of the worldwide trade in goods.[5] The Appellate Body as the WTO's permanent arbitrator has been without a quorum since December 2019. A decision to reform the WTO was reached at the 12th WTO Conference of Ministers

1 Federal Agency for Civic Education (2021): "Entwicklung des grenzüberschreitenden Warenhandels" (Development of the cross-border trade in goods). Online: https://www.bpb.de/kurz-knapp/zahlen-und-fakten/globalisierung/52543/entwicklung-des-grenzueberschreitenden-warenhandels/ (Last accessed on: 30 November 2022)

2 Deloitte (2021): "Globale Lieferketten – Kommt es zu einem Reshoring?" (Global supply chains – are we headed for a reshoring?) Online: https://www2.deloitte.com/ch/de/pages/consumer-industrial-products/articles/globale-lieferketten-kommt-es-zu-einem-reshoring.html (Last accessed on: 30 November 2022)

3 Deloitte (2021): "Globale Lieferketten – Kommt es zu einem Reshoring?" (Global supply chains – are we headed for a reshoring?) Online: https://www2.deloitte.com/ch/de/pages/consumer-industrial-products/articles/globale-lieferketten-kommt-es-zu-einem-reshoring.html (Last accessed on: 30 November 2022)

4 Caporal et al. (2019): The WTO at a Crossroad. Center for strategic & international studies (CSIS). Online: https://www.wita.org/wp-content/uploads/2019/09/190918_Caporal-et-al_WTOCrossroad_WEB_v2.pdf: (Last accessed on: 12 December 2022)

5 Federal Agency for Civic Education (2017): WTO- World Trade Organization. Online: https://www.bpb.de/kurz-knapp/zahlen-und-fakten/globalisierung/52802/wto-world-trade-organization/ (Last accessed on 14 December 2022)

in June 2022, with the intent to re-establish a functioning Appellate Body within two years[6]. Meanwhile the EU has implemented an interim solution in cooperation with 15 other WTO members. The ability of the WTO to amicably resolve trade disputes nevertheless continues to erode.

### The development of the battery industry is political

There is a high concentration of battery industry production capacities in East Asia, especially in China. This is due to the regional accumulation of battery production for electronic consumer goods and the resulting formation of an industrial ecosystem. With the rise of electric vehicles and intensive government support, the regional battery industry quickly scaled up to cover the demand for vehicle batteries. This high concentration causes technology dependencies and reduces the resilience of the European automobile industry. Consequently, subsidy policy measures with steering effects were implemented in other world regions in order to boost the production of electric vehicles and diversify the market. Examined below are the government intervention in China, Europe and the USA, which represent the leading sales markets for electric vehicles in 2021, in this order.

**China:** Electromobility and the battery industry have been supported by the government in China for a long time. Today the country has the largest sales market thanks to subsidies for electric vehicles, which favoured a rapid expansion of the manufacturing base in China over the last ten years. Battery cell manufacturing in China also expanded significantly during this time. Chinese cell manufacturers currently have the world‘s highest cell manufacturing capacities by far. Their share of the global market was around 70% in 2021.[7] Chinese companies also dominate many other segments of the value chain, such as component manufacturing or the supply chains for relevant raw materials such as lithium, cobalt, nickel and especially graphite.

In October 2020 China announced the goal that NEVs (BEV, PHEV and FCEV) will account for 20% of new passenger vehicle sales in 2025.[8] China is employing various political tools to accelerate the electrification of transportation and reach the target NEV percentage, including a flexible tax policy and subsidies. With 3.3 million electric passenger vehicles (BEV and PHEV), considerably more vehicles were sold in China in 2021 than in Europe, where 2.3 million vehicles were sold in the same year[9]. According to CAAM (China Association of Automobile Manufacturers), the share of NEVs in new registrations exceeded the target set for 2025 already in the first half of 2022.

The Chinese government is no longer subsidising electric vehicle (EV) buyers effective on January 1st, 2023. Some measures to support EV sales remain in place, for example EV buyers can claim a ten percent VAT exemption until the end of 2023. Also, the credit system for environmentally friendly cars that establishes annual compliance requirements for automobile manufacturers remains. Companies that exceed the EV proportion target in their vehicle fleet can sell excess credits, while those that fall short have to buy credits or pay a fine.[10]

**Europe:** The EU deem the promotion of developing a European battery industry a strategic necessary and views batteries as a key technology to ensure the competitiveness of its automobile industry. Therefore, the EU is pursuing the goal established in the industrial policy strategy to restore Europe‘s position as a leader in a key industry that is fit for the future. This promotes both employment and growth within the recycling economy, as well as ensuring clean mobility, a healthier environment and better quality of life for EU citizens.[11] The goal is to supply the European automobile industry with sustainably produced batteries by 2030 A second aspect is to strengthen the automobile industry by establishing an innovative European battery ecosystem, in which companies and research institutions transfer innovations from research to production. Moreover, the dependency on imports, especially in the vehicle battery segment has to be reduced. These measures do not exclude non-European stakeholders from the domestic market per se – neither regarding financial subsidies nor through regulation.

6 World Trade Organization (2022): Members welcome MC12 commitment to address dispute settlement. Online: https://www.wto.org/english/news_e/news22_e/dsb_30jun22_e.htm (Last accessed on: 14 December 2022)

7 SNE Research (2022): Production Capacity of Global EV Battery Makers Forecasted to Reach 8,247GWh in 2030. Online: https://www.sneresearch.com/en/insight/release_view/17/page/12 (Last accessed on: 12 December 2022)

8 ICCT (2021): A GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF COMBUSTION ENGINE AND ELECTRIC PASSENGER CARS (Last accessed on: 12 December 2022)

9 IEA (2022): Electric Vehicle Outlook 2022. Online: https://iea.blob.core.windows.net/assets/ad8fb04c-4f75-42fc-973a-6e54c8a4449a/GlobalElectricVehicleOutlook2022.pdf (Last accessed on: 12 December 2022)

10 https://chinadialogue.net/en/digest/china-ends-electric-vehicle-subsidies/ (Last accessed on: 12 December 2022

11 COM (2018) 293 final: EUROPE ON THE MOVE – Sustainable Mobility for Europe: safe, connected and clean ANNEX 2 “Strategic Action Plan on Batteries”

With the Important Project of Common European Interest (IPCEI) funding instrument, two large-scale programmes were launched in 2019 and 2021 for the establishment of a sustainable battery value chain in Europe with a funding volume of 3.2 and 2.9 billion euros, respectively.[12] The EU Commission placed great emphasis on conformity with the WTO rules in designing these funding instruments. That is significant because this market-oriented funding has to range in the limits given by WTO rules regarding the permission to support the industry.

In addition, regulations are also being prepared in the EU aiming to significantly increase and diversify the supply of critical raw materials, to strengthen the recycling economy, and to support research and innovation. The European Battery Regulation will ensure compliance with especially strict sustainability requirements for batteries/battery cells produced and traded in Europe.[13] A regulation to safeguard the supply of critical raw materials, thereby reducing the EU's strategic dependencies, is being sought through the European Critical Raw Materials Act.[14] The EU member states have also agreed on a new EU Supply Chain Law on December 1st, 2022. It will require companies to exercise diligence with regard to social and ecological effects in the entire supply chain, including their own business area.[15]

**USA:** Several laws have been passed in the USA since 2021, jointly earmarking several hundred billion US dollars for climate protection, the transformation of the energy supply, and infrastructure development and expansion. This will benefit the battery industry along the entire value chain as well as electric vehicle manufacturers. For example, the Bipartisan Infrastructure Law[16] provided 2.8 billion US dollars in October 2022 to support domestic commercial enterprises for the extraction and processing of lithium and graphite and for battery manufacturing. In March 2022, the US President with reference to the Defence Production Act (DPA) authorised the Department of Defence (DoD) to boost the extraction and processing of important materials for the large battery supply chain in the country. Additionally, the US Congress passed the greatest climate law in our country's history in the summer of 2022, the so-called law for the reduction of inflation.[17] The Inflation Reduction Act (IRA) earmarks 368 billion US dollars, among other things to promote clean energy generation, emission-free vehicles and clean industrial processes as well as manufacturing methods. According to the current form, the law calls for tax credits of up to 50% for autonomous energy storage and 7,500 US dollars for emission-free vehicles. Tax credits for the domestic production and sale of qualified components such as batteries are also provided.

The imposed restrictions, for instance in case of granting tax credits for electric vehicles, appear to be protectionist and cause resentment internationally. Among other things, it is presumed that final production of the vehicles will take place in North America and that their traction batteries are made using components from certain countries. Around 200 billion euros (207 billion dollars) of the IRA's total funding volume is tied to provisions regarding locally produced content, which in the EU's opinion may violate the rules of the World Trade Organisation (WTO).[18] However, the EU is not the only organisation speaking out against the new law. China has criticised the new law and threatened to take unspecified steps to protect its interests against the "discriminatory" law. South Korea also fears that its automobile manufacturers will not benefit from the US tax breaks.[19]

### Demand for batteries will multiply

In view of the market volume and its expected growth, substantial politico-economic steps to guide the development and expansion of the battery industry obviously have to be taken. The global market for lithium-ion batteries (LIB) has been estimated at around USD 42 billion in 2021. McKinsey analysts expect a growth of more than 20% annually until

12 European Commission announcements. Online: https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705 and https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226 (Last accessed on: 30 November 2022)

13 EU Parliament (2022): New EU rules for more sustainable and ethical batteries. Online: https://www.europarl.europa.eu/news/en/headlines/economy/20220228STO24218/new-eu-rules-for-more-sustainable-and-ethical-batteries (Last accessed on: 30 November 2022)

14 EU Commission (2022): European Critical Raw Materials Act. Online: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13597-European-Critical-Raw-Materials-Act_en (Last accessed on: 30 November 2022)

15 Deutsche Presse-Agentur (2022): "EU-Staaten einig bei Lieferkettengesetz" (EU states agree on supply chain law). Online: https://europeannewsroom.com/de/eu-staaten-einig-bei-lieferkettengesetz/ (Last accessed on: 14 December 2022)

16 President Biden's Bipartisan Infrastructure Law. Online: https://www.whitehouse.gov/bipartisan-infrastructure-law/ (Last accessed on: 30 November 2022)

17 Inflation Reduction Act of 2022. Online: https://www.congress.gov/bill/117th-congress/house-bill/5376/text (Last accessed on: 30 November 2022)

18 Reuters (2022): Explainer: Why the U.S. Inflation Reduction Act has Europe up in arms. Online: https://www.reuters.com/markets/why-us-inflation-reduction-act-has-europe-up-arms-2022-11-30/ (Last accessed on: 1 December 2022)

19 EU seeks changes to 'discriminatory' U.S. Inflation Reduction Act. Online: https://www.cbtnews.com/eu-seeks-changes-to-discriminatory-u-s-inflation-reduction-act/ (Last accessed on: 1 December 2022)

2030, reaching at least 360 billion dollars globally by the end of the decade.[20]

According to Adamas Intelligence, the battery capacity installed in all new electric vehicles for passenger transportation which was sold worldwide in the first six months of 2022 increased by 79% year-on-year to a total of nearly 200 GWh.[21] The research and advisory service's market analysis shows that the global production capacities of cell manufacturers could increase from around 600 GWh/a currently to more than 6,000 GWh/a by 2030 if projects that have been announced are fully realised.

Due to the rising demand for and production of LIBs, start-ups are appearing in the supply chain alongside established battery cell suppliers. At the same time, automobile industry OEMs are diversifying their suppliers, increasing LIB production or deciding to operate their own gigafactories. In some cases they are even concluding contracts with mining companies for the supply of raw materials. These companies are therefore become highly vertically integrated and are able to influence large parts of the value chain.

**Battery industry supply chains are highly complex**

A successfully established electromobility is determined to a large extent by the price of the battery which is the most expensive component of an electric vehicle accounting for up to 50% of the total cost. In the production of LIBs the mayor share of the total battery costs are accounted for material costs. Each LIB consists of the same basic components – the battery case, positive electrode (cathode), negative electrode (anode), electrolyte and separator. The pie chart in the middle of Figure 1 shows the component materials by the proportion of weight for an exemplary battery cell. The cathode material is the most expensive component of a battery cell, accounting for around 60% of the material costs along with the anode material. While the anode is generally made of natural and artificial graphite, varying composition of lithium metal oxides can be applied for the cathode. Depending on the cell technology which is required for the battery cell manufacturing, the corresponding raw materials are varying. Consequently, the raw material supply chains for battery cell manufacturing are diverse. This study identified 95 raw and intermediate products along the value chain for the most common cell technologies – NMC, NCA and LF(M)P – ranging from the raw material to the precursors applied during battery cell manufacturing (see Figure 1).

Figure 1 visualises the globally traded intermediate products relevant for the battery cell manufacturing value chain starting from the raw material (outer ring) over to refined and intermediate products up to the precursors for manufacturing battery cells based on the common cathode materials NMC, NCA and LF(M)P as well as natural/artificial graphite for the anode material (inner ring). The pie chart in the centre shows the material components according to the proportion of weight for an exemplary battery cell. It should be noted that the intermediate products are traded in various quality levels and with different specifications. Only a part of the intermediate products available or traded in the market is actually suitable for battery cell manufacturing.

**No dominant cell technology**

The most frequently used LIBs installed in electric vehicles are made from battery cells consisting of nickel manganese cobalt mixed oxide (NMC) as cathode active material and graphite as anode active material. More than half of the cell volume of nearly 200 GWh installed in the first half of 2022 was based on the NMC technology.[22] However, the use of lithium-iron phosphate (LFP) batteries has been steadily increasing recently. Their share according to Adamas Intelligence was around 53 GWh in the first half of 2022 (27% of the total volume). Other shares accounted for NCA and LMO technologies.

Cells based on NMC cathodes will continue to play an important role in batteries for electromobility. Consequently, their components lithium, nickel, manganese, cobalt and graphite (natural and artificial) are not only essential for the functionality of an NMC cell, but also linked directly to the success of electromobility due to the cost factor. They are therefore the object of this study. Other cell components such as aluminium, for example, are not examined in detail in this study since their supply situation and price development are currently non-critical.

20 McKinsey (2022): Capturing the battery value-chain opportunity. Online: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/capturing-the-battery-value-chain-opportunity (Last accessed on: 1 December 2022)

21 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022

22 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022

## 2.1 Focus on five battery raw materials

The raw materials lithium, nickel, manganese, cobalt and graphite (natural and artificial) have supply chains of varying complexity, which are specifically examined in this study due to their economic importance and their relevance for the ecological balance of battery cells. As illustrated by the overview of the supply chains for raw materials, precursors and intermediate products for battery cell manufacturing (Figure 1), certain precursors can be produced using various intermediate products. Nickel sulphate, for example, can be made from various precursors such as nickel matte, nickel metal or MSP/MHP containing nickel. Other preliminary products on the other hand can only be produced from a specific intermediate product (for example natural graphite). For some raw materials (for example lithium, cobalt and graphite), the battery cell manufacturing will very soon account to the largest proportion of their utilisation (starting in 2030). For other raw materials, the proportions will be lower (e.g. nickel) or even in the tenth of one per cent (e.g. manganese) of the world trade. Some raw materials are bulk commodities (nickel and manganese, for example). However, these markets become considerably smaller and more specialised along with further processing (high-purity nickel or manganese sulphate, for example). The examined raw materials are presented below with regard to their geographical, economic and technological characteristics.

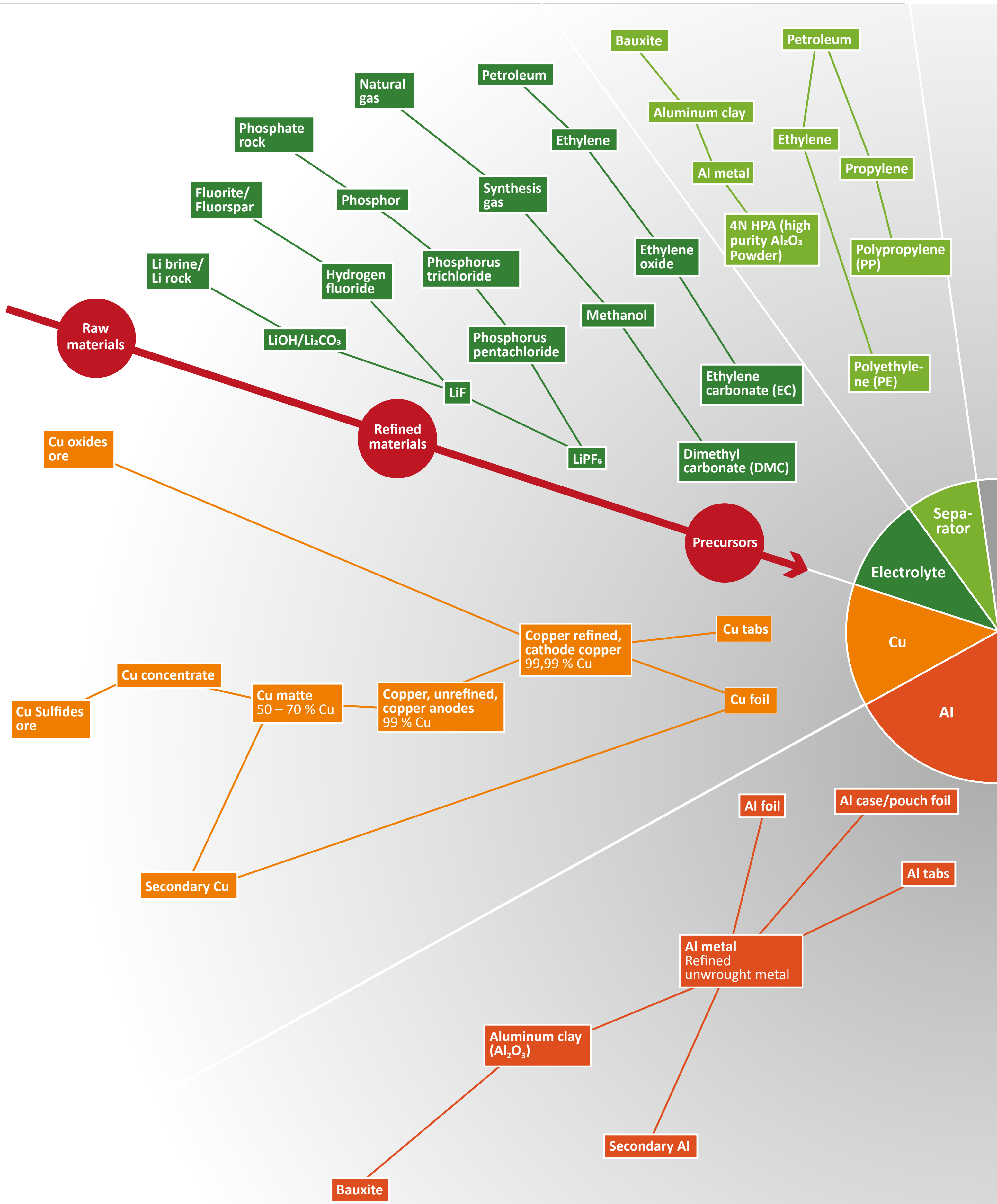
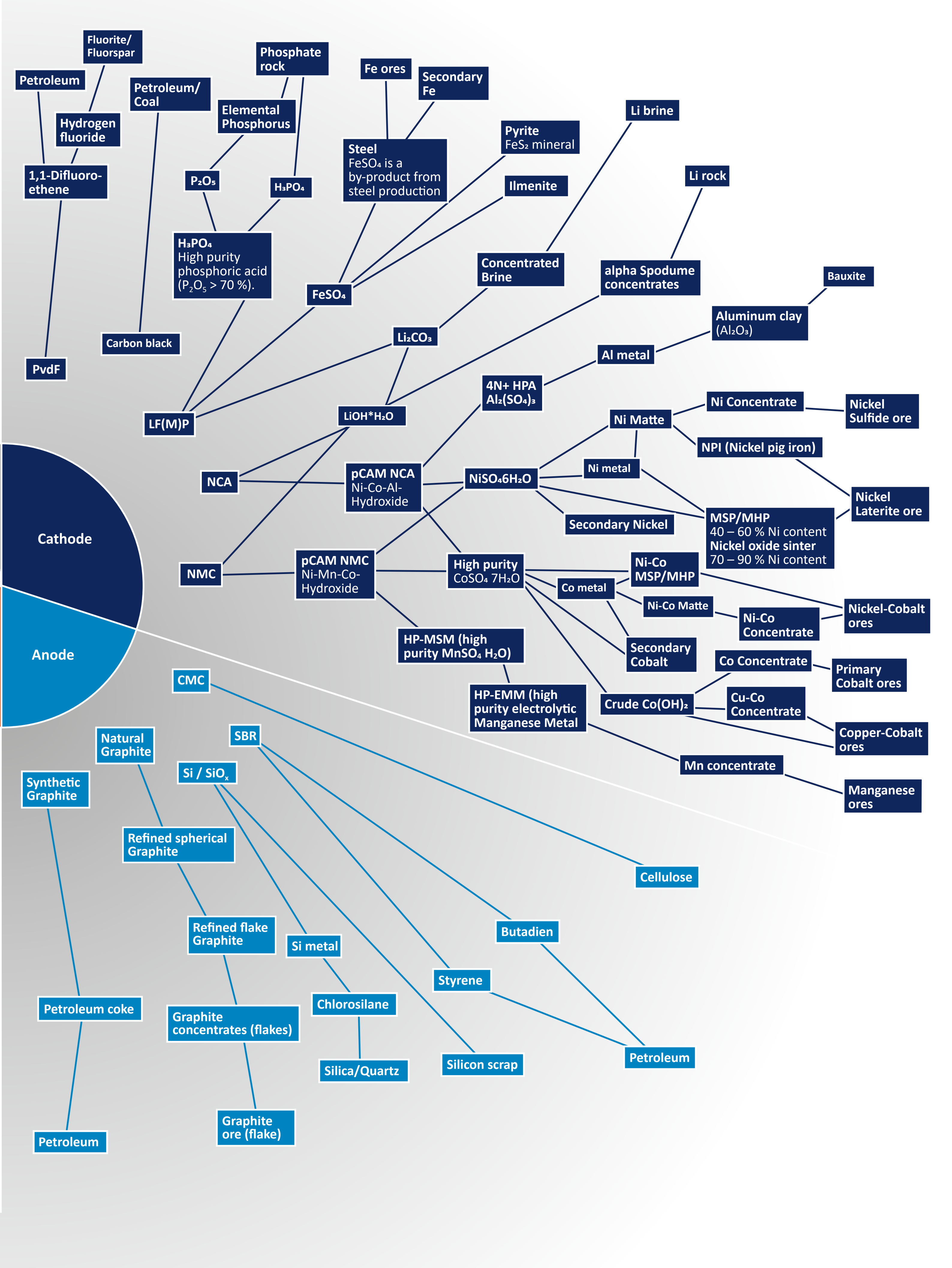



Figure 1: Graphical overview of supply chains in battery cell manufacturing; examined intermediate products in the supply chain from the raw material to refined and intermediate products to the precursors for battery cell manufacturing. The diagram in the centre shows the material components of an exemplary battery cell according to their weight proportions (*own assumptions). In-house representation.


Cathode
Anode
Fluorite/ Fluorspar
Petroleum
Hydrogen fluoride
1,1-Difluoro-ethene
PvdF
Petroleum/ Coal
Carbon black
Phosphate rock
Elemental Phosphorus
$P_2O_5$
$H_3PO_4$
$H_3PO_4$ High purity phosphoric acid ($P_2O_5$ > 70 %).
Fe ores
Secondary Fe
Steel $FeSO_4$ is a by-product from steel production
Pyrite $FeS_2$ mineral
Ilmenite
$FeSO_4$
LF(M)P
Li brine
Li rock
Concentrated Brine
alpha Spodume concentrates
$Li_2CO_3$
$LiOH*H_2O$
Bauxite
Aluminum clay ($Al_2O_3$)
Al metal
4N+ HPA $Al_2(SO_4)_3$
NCA
pCAM NCA Ni-Co-Al-Hydroxide
Ni Concentrate
Nickel Sulfide ore
Ni Matte
NPI (Nickel pig iron)
Ni metal
$NiSO_4 6H_2O$
Nickel Laterite ore
Secondary Nickel
MSP/MHP 40 – 60 % Ni content Nickel oxide sinter 70 – 90 % Ni content
NMC
pCAM NMC Ni-Mn-Co-Hydroxide
High purity $CoSO_4$ $7H_2O$
Ni-Co MSP/MHP
Co metal
Ni-Co Matte
Nickel-Cobalt ores
Ni-Co Concentrate
Secondary Cobalt
HP-MSM (high purity $MnSO_4$ $H_2O$)
Co Concentrate
Primary Cobalt ores
HP-EMM (high purity electrolytic Manganese Metal
Crude $Co(OH)_2$
Cu-Co Concentrate
Copper-Cobalt ores
Mn concentrate
Manganese ores
CMC
Cellulose
SBR
Natural Graphite
Si / $SiO_x$
Synthetic Graphite
Refined spherical Graphite
Refined flake Graphite
Si metal
Butadien
Styrene
Chlorosilane
Petroleum coke
Graphite concentrates (flakes)
Silica/Quartz
Silicon scrap
Petroleum
Graphite ore (flake)
Petroleum

### 2.1.1 Lithium

**Raw material characteristics and sources.** Lithium in its pure form is the lightest solid element. It is highly reactive and therefore does not exist in nature as a pure metal, but exclusively in the form of lithium salts. The salts are found as solids in form of minerals or dissolved in solutions, for example, in salt lakes. Lithium is currently mined only from land reserves in the form of ores and brines amount to approximately 22 million tons (Lithium content) worldwide. Global ressources are estimated to approimately 89 Mio. t (Lithium content). South America holds more than half of these resources, in particular Bolivia (21 million tons), Argentina (19 million tons) and Chile (10 million tons).[23]

**Extraction and refining.** In 2021 approximately 105 kt lithium (content) were mined worldwide. Australia, Chile and China account for around 90% of the global production from which 60% of production is mined as hard rock and 40% as brines.[24]

Processing lithium into battery precursors such as lithium carbonate and lithium hydroxide is very complex, depending on the level of impurities, and requires multiple chemical processes. 58% of the total lithium extraction volume was refined in China in 2021 and 30% in Chile. The country concentration for lithium processing is therefore high (HHI 4,264).

**Main application and demand for batteries.** Lithium battery production is the main application for lithium (70%). Other typical applications for lithium are ceramics and glass production (15%), lubricants (4%) and metallurgy processes (2%).[25] A 75 kWh battery consisting ofNMC622 cells contains around 9 kg of lithium which means that producing one GWh of this cell type requires about 118 t of lithium. According to Adamas Intelligence, approximately 117 kt of lithium carbon equivalents (LCE) were used worldwide for batteries installed in new electric vehicles which were sold for passenger transport in the first half of 2022. This corresponds to a 76% increase compared to the prior year. [26]

**Market development.** The lithium demand for battery cell manufacturing will be up to 21 times higher in 2030 compared to 2021. In this case, the demand for cell manufacturing alone would equal approximately seven times the total global lithium supply of 2020.

After the price of lithium was falling for two year, it increased significantly in 2021 and rose disproportionally at the beginning of 2022. In contrast to other raw materials, the price level for lithium remained at this very high level in recent months.

23 Schmidt, M. (2023): “Rohstoffrisikobewertung – Lithium. – DERA Rohstoffinformationen 54” (Raw material risk assessment – Lithium. DERA raw material information 54): 81 pages, Berlin (Last accessed on: 3 February 2022)

24 Schmidt, M. (2022): “Rohstoffrisikobewertung – Lithium 2030 – Update” (Raw material risk assessment – Lithium 2030 – Update) (Last accessed on: 12 December 2022)

25 https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf (Last accessed on: 12 December 2022)

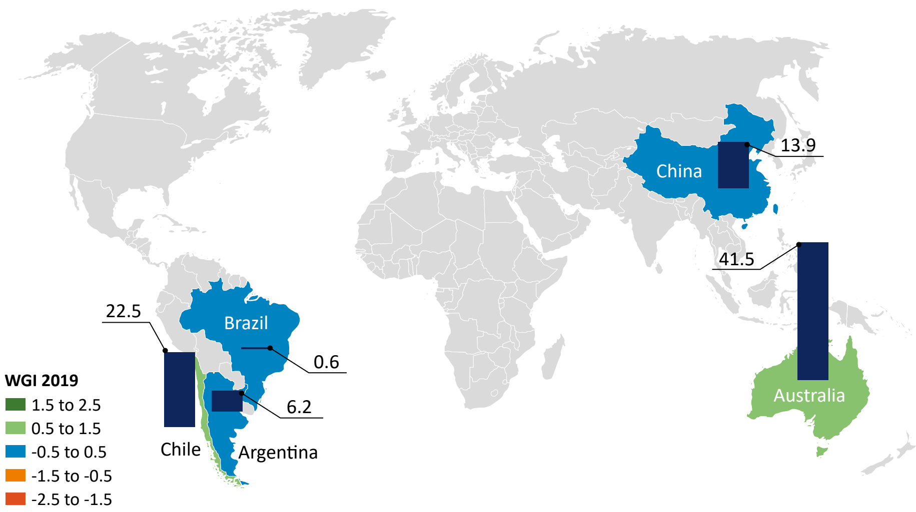
26 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022

Li

# Fact Sheet Lithium

## Global Mining

(Lithium content in kt)

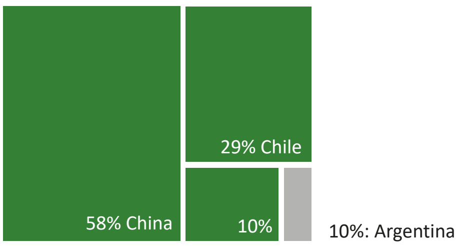



## Perspective

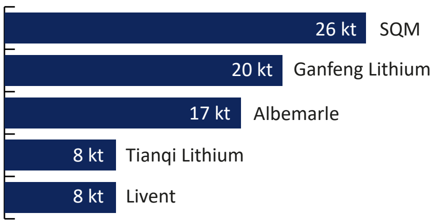
The demand for lithium will increase enormously by 2030. Accordingly, the extraction of raw materials must be expanded. If projects are not implemented as planned, there will be a significant deficit by 2030.[I]

## Refining

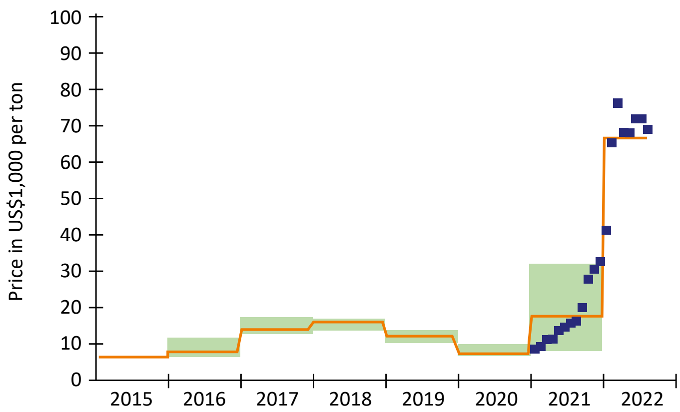
**Countries with the largest market shares**




**Relevant lithium producers (capacity, 2021)**

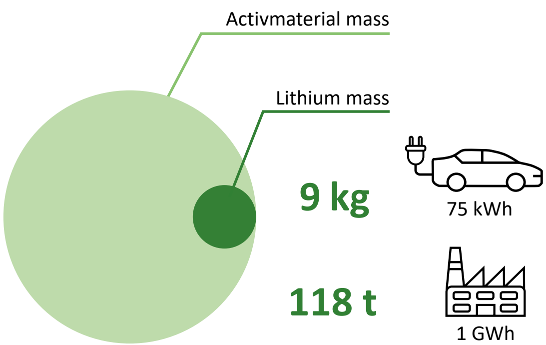


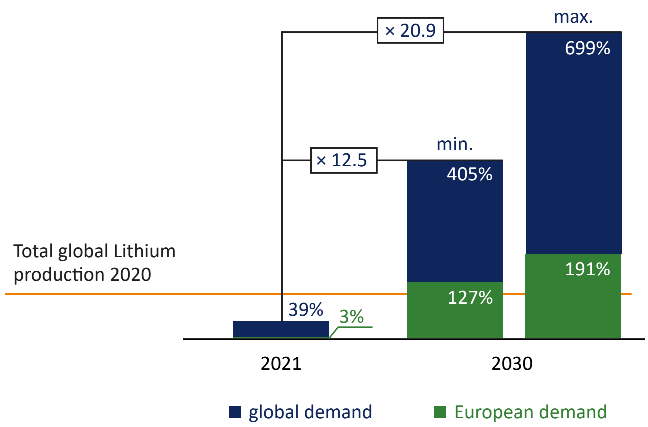

## Price monitor




**Ø Sep 2021–Aug 2022:** 54,621
**Ø 2015–2021:** 11,748 (364.9 %)

## Demand for battery cells




I McKinsey (2023); Battery 2030: Resilient, sustainable, and circular; https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular#/

### 2.1.2 Nickel

**Raw material characteristics and sources.** Nickel is the fifth most abundant element on earth.[27] It mainly occurs in nature in combination with iron and sulphur as well as in the form of nickel-laterite ores which are typically formed by geological processes in tropical regions. There are large deposits in the Philippines and Indonesia among others.[28] Global nickel resources are estimated at nearly 300 million tons. Similar levels are assumed to be found at the bottom of the world's oceans.[27] Even though the nickel content is low, the extraction of laterite ores has increased considerably in recent years due to a high demand as well as improved processing techniques. To this day, nickel-rich pentlandite serves as one of the most important nickel sources due to its high nickel content which makes it a better precursor for the battery industry.

**Extraction and refining.** Around 2.58 million tons of nickel ore were mined globally in 2021. With about 60%, the majority of Nickel mining takes place in the West Pacific region. More than half the total mining volume was refined in China (748 kt) and Indonesia (645 kt). Even though two companies stand out with very high production capacities, the market concentration is only moderate.

**Main application and demand for batteries.** The high demand for nickel results from a sharp increase in global sales of electric vehicles associated by an elevated average sales-weighted battery capacity. Due to the efforts to substitute cobalt with nickel as component in cathode materials the use of cathodes with a moderate or high nickel content become more common. Nevertheless, the use of nickel in battery materials only accounted for slightly more than 11% in 2021 according to the Nickel Institute.[29] More than two thirds of the annual global nickel production is applied for the production of stainless steel.

A 75 kWh battery consisting of NMC622 cells contains about 40 kg of nickel which means that producing one GWh of this cell type requires about 532 t of nickel. According to Adamas Intelligence, approximately 88 kt of nickel was used worldwide for batteries installed in new electric vehicles which were sold for passenger transport in the first half of 2022. This corresponds to a 50% increase compared to the prior year. [30]

**Market development.** The nickel demand for battery cell manufacturing will be up to 17 times higher by the end of the decade compared to 2021. In this case, the demand for cell manufacturing alone would equal approximately 80% of the total global nickel supply of 2020. According to the rising demand, the price of nickel increased significantly in 2021 after remaining constant for two years and rose sharply at the beginning of 2022. After the nickel price reached a maximum in March of this year, it fell again and is currently around the level of the end of 2021.

27 https://nickelinstitute.org/en/about-nickel-and-its-applications/ (Last accessed on: 12 December 2022)

28 https://www.statista.com/statistics/273634/nickel-reserves-worldwide-by-country/ (Last accessed on: 12 December 2022)

29 https://nickelinstitute.org/en/about-nickel-and-its-applications/#04-first-use-nickel (Last accessed on: 12 December 2022)

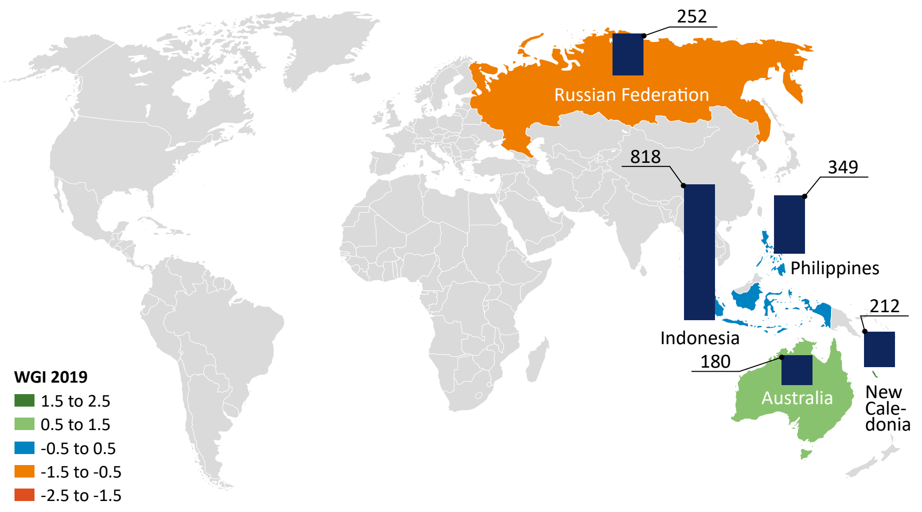
30 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022 (Last accessed on: 12 December 2022)

Ni

# Fact Sheet Nickel

## Global Mining

(Nickel content in kt)

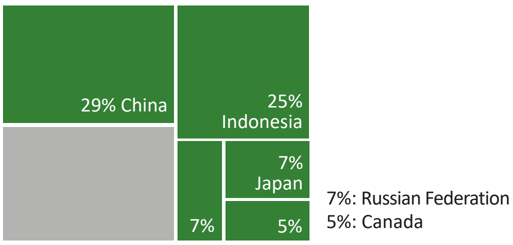



## Perspective

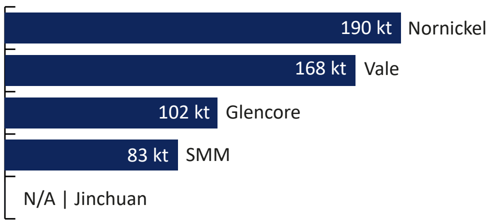
In the case of nickel, only a smaller deficit is to be expected by 2030.
New mining projects and the increasing use of LFP could lead to supply and demand balancing out by 2030.[II]

## Refining

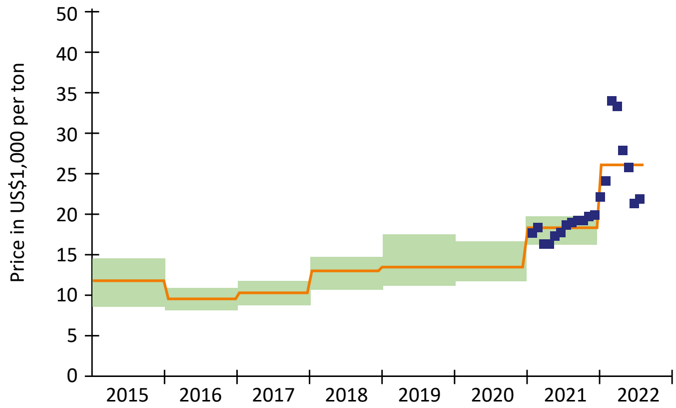
**Countries with the largest market shares**




**Relevant nickel producers (production, 2021)**



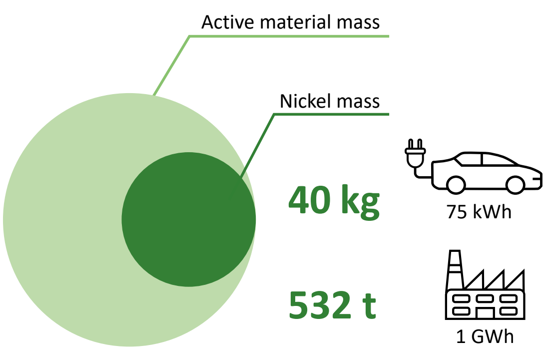

## Price monitor

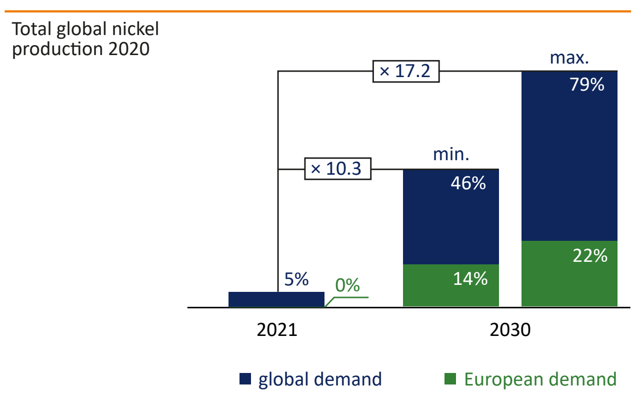



**Ø Sep 2021–Aug 2022:** 24,121
**Ø 2015–2021:** 13,014 (↗ 85.4 %)

annual mean
min/max area
monthly mean

## Demand for battery cells




II McKinsey (2023); Battery 2030: Resilient, sustainable, and circular; https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular#/

### 2.1.3 Manganese

**Raw material characteristics and sources.** Manganese is typically found in nature as pyrolusite (manganese dioxide), braunite (manganese silicate) and psilomelane (mixture of various manganese oxides). Worldwide manganese reserves total approximately 1.5 billion tons. The largest deposits are found in South Africa (43%), Brazil (18%) and Australia (18%).

**Extraction and refining.** South Africa (36%), Gabon (18%) and Australia (17%) are currently the extraction leaders. China is currently the world's largest importer of more than 70% manganese ore and the leading producer of intermediate products for battery manufacturing.[31] One company stands out with a very high production capacity, resulting in an elevated market concentration.

**Main application and demand for batteries.** Only about 0.2% of global manganese extraction is currently used for lithium-ion batteries. The demand for manganese is largely dominated by the steel industry, which accounts for around 90% of the world's manganese production.[32] However, the battery industry is steadily gaining importance as a field of application for manganese due to the increasing use of NMC batteries.

A 75 KWh battery consisting of NMC622 cells contains around 12 kg of manganese which means that producing one GWh of this cell type requires about 165 t of manganese. According to Adamas Intelligence, approximately 24 kt of manganese was used worldwide for batteries installed in all new electric vehicles which were sold for passenger transport in the first half of 2022. This corresponds to a 44% increase compared to the prior year.[33] The increased demand for manganese is mainly caused by rising numbers of global EV sales and higher average battery capacities. The demand for battery cells with a lower cobalt content has increased as well due the availability of NMC cathodes with higher proportions of nickel and manganese.

**Market development.** The manganese demand for battery cell manufacturing will be up to 11 times higher by the end of the decade compared to 2021. In this case, the demand for cell manufacturing alone would equal approximately 1.3 times the total global manganese supply of 2020.

In keeping with rising demand, the price of manganese increased slightly in 2020 after declining for two years, and rose sharply in 2021. The price of manganese reached a high point at the end of 2021, then fell again this year and is currently near the level from the start of 2021 and the average for 2020.

31 https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Downloads/rohstoffsteckbrief_mn.pdf?__blob=publicationFile&v=3/ (Last accessed on: 12 December 2022)

32 https://www.deutsche-rohstoffagentur.de/DERA/DE/Aktuelles/rohstoff_mangan.html?nn=5091226 (Last accessed on: 12 December 2022)

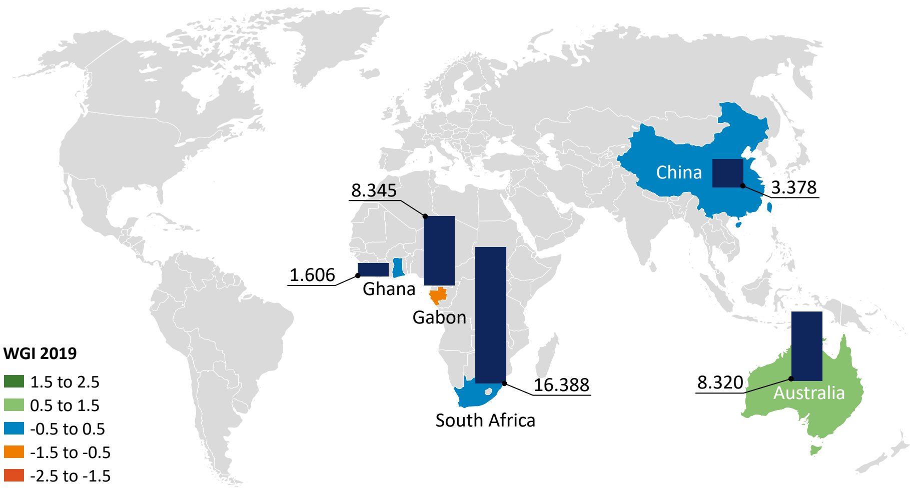
33 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022

Mn

# Fact Sheet Manganese

## Global mining

(Manganese ore in kt)

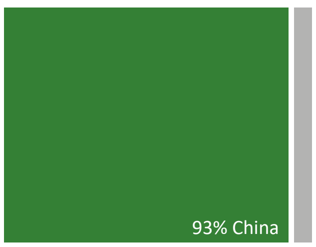



## Perspective

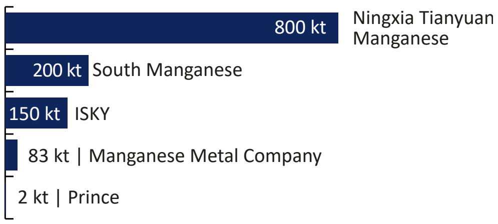
The manganese supply situation could remain stable until 2030. Assuming high-nickel NMC and LFP dominate, manganese demand should increase comparatively little. The demand for manganese could increase significantly if LMFP or manganese-rich NMC are used more extensively.[III]

## Refining

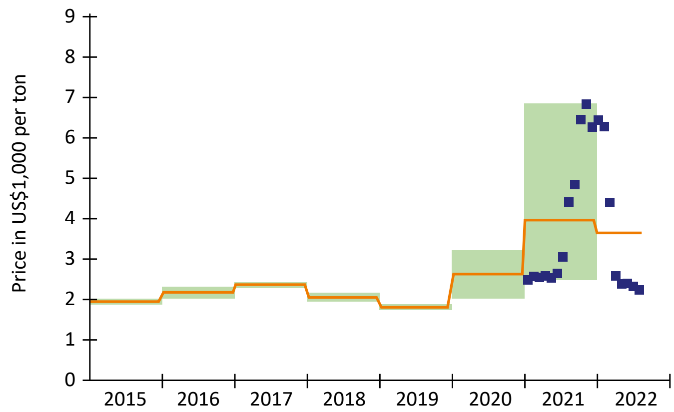
**Countries with the largest market shares**




**Relevant manganese producers (capacity, 2021)**



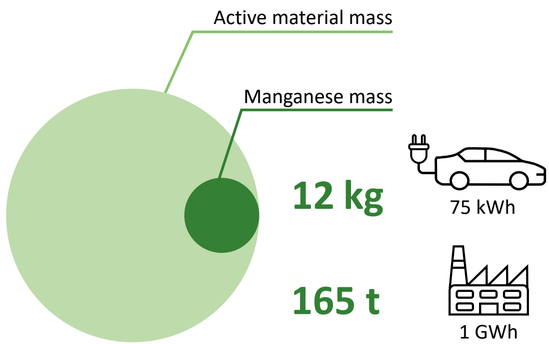

## Price monitor

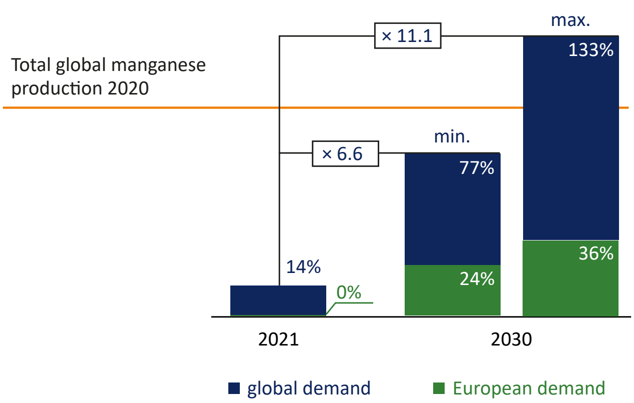



**Ø Sep 2021–Aug 2022:** 4,453
**Ø 2015–2021:** 2,403 (85.3 %)

annual mean
min/max area
monthly mean

## Demand for battery cells




III McKinsey (2023); Battery 2030: Resilient, sustainable, and circular; https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular#/

### 2.1.4 Cobalt

**Raw material characteristics and sources.** Cobalt does not occur naturally in its pure form, but only in the form of minerals containing cobalt. In general, cobalt is not mined directly, but occurs largely as a by-product from copper and nickel production. Global land-based cobalt resources are estimated at 25 million tons. Another 120 million tons are assumed to be found at the bottom of the world's oceans. The largest reserves are located in the Democratic Republic of the Congo (3.5 million tons) and Australia (1.4 million tons).

**Extraction and refining.** The Democratic Republic of the Congo not only has the largest deposits of cobalt ore but is also the leader in cobalt mining. Around 69% of cobalt mined globally in the form of ore in 2020 (142 kt) came from the Congo (98 kt). Considerably smaller volumes were produced in Russia (9 kt) and Australia (5.6 kt).[34] China is the largest producer of refined cobalt with a market share of around 72% in 2021.[35] More than 80% of China's cobalt production is used in the country's own production of lithium-ion batteries.[34] As there are three companies with high production capacities the market concentration is elevated.

**Main application and demand for batteries.** The metal industry was the main field of application for cobalt until a few years ago. Rechargeable batteries, in which cobalt is used as a component of the cathode materials, are the largest growth driver on the demand side. A 75 kWh battery consisting of NMC622 cells contains around 13 kg of cobalt which means that producing one GWh of this cell type requires about 177 t of cobalt. According to Adamas Intelligence, approximately 19 kt of cobalt was used worldwide for batteries installed in new electric vehicles which were sold for passenger transport in the first half of 2022. This corresponds to a considerable 44% increase compared to the prior year.[36]

**Market development.** The cobalt demand for battery cell manufacturing will be up to 15 times higher by the end of the decade compared to 2021. In this case, the demand for cell manufacturing alone would equal approximately 3.6 times the total global cobalt supply of 2020.

After the cobalt price increased significantly in 2017 and 2018, it fell to around the level of the prior years before rising again in 2021. Corresponding to rising demand, the price of cobalt increased further at the beginning of 2022. After reaching a high point in April 2022, the price of cobalt recently fell significantly again and is currently below the average from 2021.

34 https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-cobalt.pdf (Last accessed on: 12 December 2022)

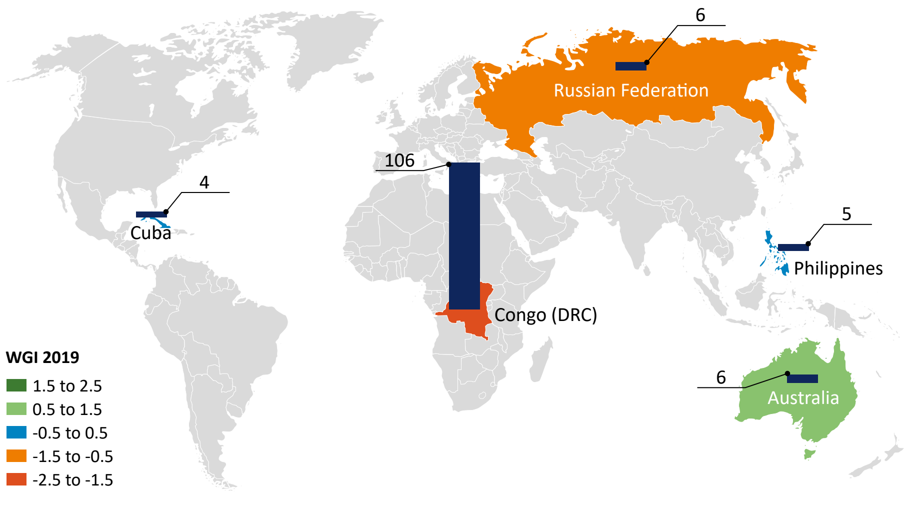
35 Cobalt Institute (2022): Cobalt Market Report 2021. Online: (Last accessed on: 14 December 2022)

36 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022

Co

# Fact Sheet Cobalt

## Global mining
(Cobalt content in kt)

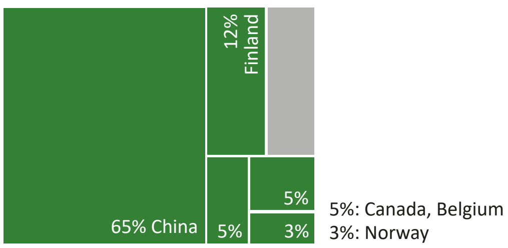



## Perspective

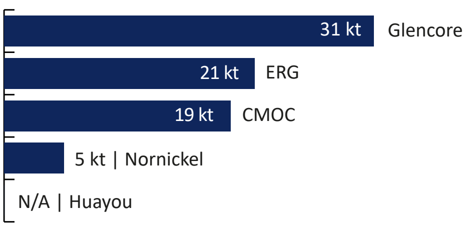
The relative fraction of cobalt in LIB will decrease by 2030. In addition, raw material supply will increase as new copper and nickel projects come online by 2030, producing cobalt as a by-product. Cobalt should therefore be sufficiently available by 2030.[IV]

## Refining

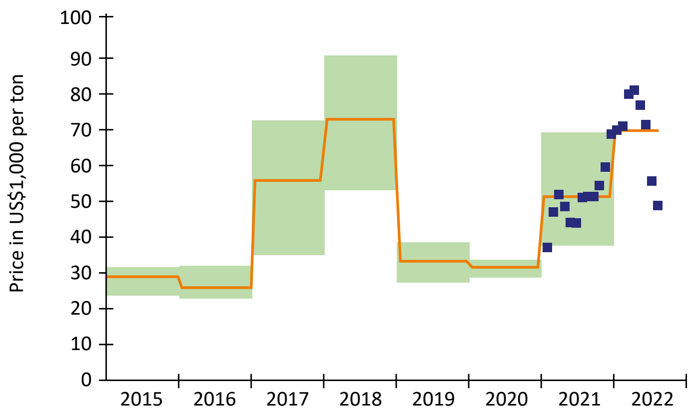
**Countries with the largest market shares**




**Relevant cobalt producers (production, 2021)**



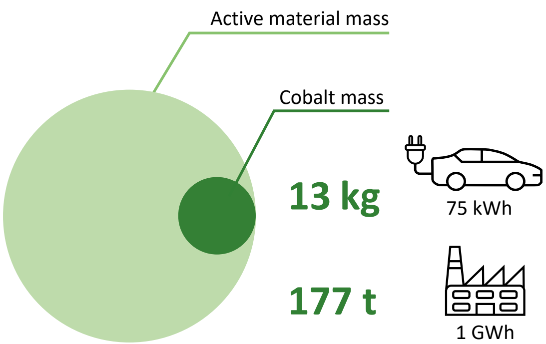

## Price monitor

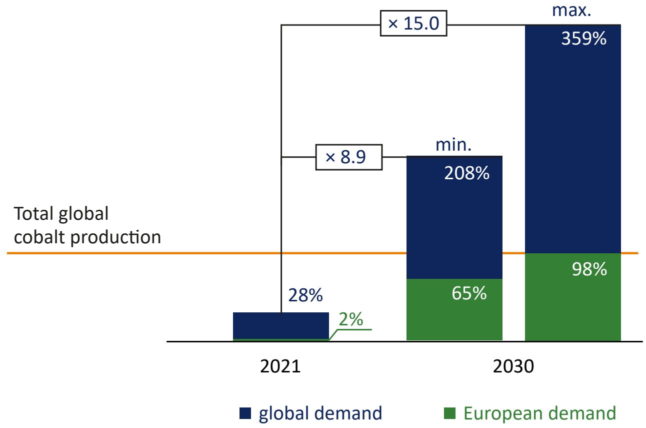



**Ø Sep 2021–Aug 2022:** 66,115
**Ø 2015–2021:** 42,507 (↗ 55.5 %)

annual mean
min/max area
monthly mean

## Demand for battery cells




IV McKinsey (2023); Battery 2030: Resilient, sustainable, and circular; https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular#/

### 2.1.5 Graphite

**Raw material characteristics and sources.** Graphite occurs in nature in the form of flakes, metamorphic rock and as veins in pegmatite. It can be produced industrially as artificial graphite as well. Natural graphite is mined while artificial graphite is produced through the coking of precursors containing carbon, such as coal and crude oil. Both natural and artificial graphite are used in battery cell manufacturing.

**Extraction and refining.** Around 1.7 million tons of natural graphite was mined worldwide in 2019. The production volume of artificial graphite was around 1.6 million tons in 2018.[37] With a nearly 74% share of natural graphite production and about half the artificial graphite, China is the world's leading producer.[38] Madagascar, Mozambique and Brazil are other important mining countries for natural graphite. Japan, the USA, India and Europe are important producers of artificial graphite. One company with a very high production capacity stands out and thus the market concentration is moderate.

**Main application and demand for batteries.** The main areas of application for graphite in 2018 were electrodes (750 kt) and fireproof products (475 kt). According to Adamas Intelligence, approximately 177 kt of graphite was however used worldwide for batteries installed in new electric vehicles which were sold for passenger transport in the first half of 2022. This corresponds to an 86% increase compared to the prior year.[39] A 75 kWh battery consisting of NMC622 cells contains around 66 kg of graphite which means that producing one GWh of this cell type requires about 884 t of graphite.

**Market development.** The graphite demand for battery cell manufacturing will be up to 23 times higher by the end of the decade compared to 2021. In this case, the demand for cell manufacturing alone would equal approximately 1.6 times the total global graphite supply of 2020.

The price of graphite has been increasing since 2019 in keeping with rising demand, with a significantly sharper increase in 2021. After the graphite price reached a high point in April 2022, it recently dropped slightly again.

37 Damm, S. (2021): "Rohstoffrisikobewertung – Graphit. – DERA Rohstoffinformationen , 51" (Raw material risk assessment – Graphite. DERA raw material information 51): 116 pages; Berlin.

38 DERA (2021): "Batterierohstoffe für die Elektromobilität. – DERA Themenheft" (Battery raw materials for electromobility. – DERA special issue): 26 pages; Berlin.

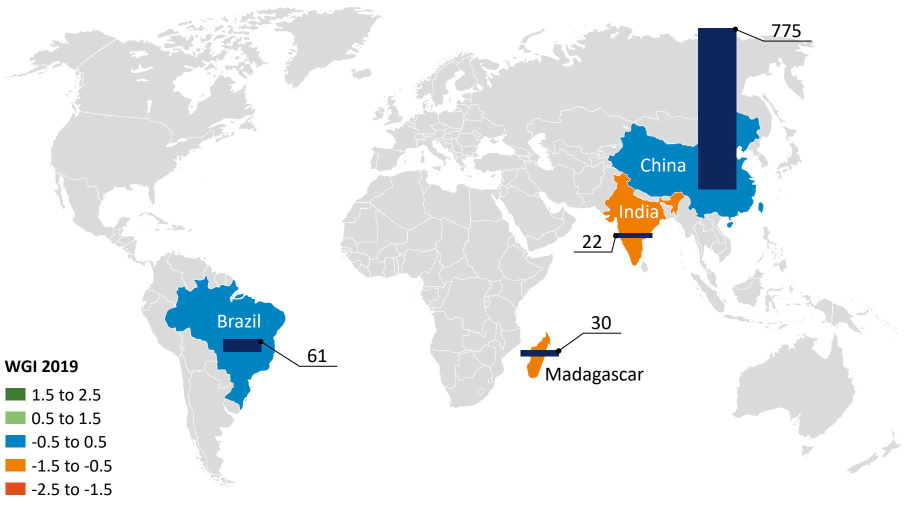
39 Adamas Intelligence: State of Charge: EVs, Batteries and Battery Materials, 2022

C

# Fact Sheet Graphite

## Global mining

(Graphite content in kt)



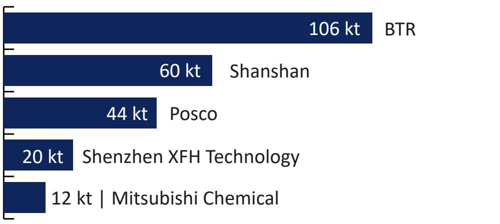

## Perspective

Supply and demand could balance out until 2030, especially because natural graphite can be substituted by synthetic graphite. Synthetic graphite offers the advantage that it can be produced on demand.[V]

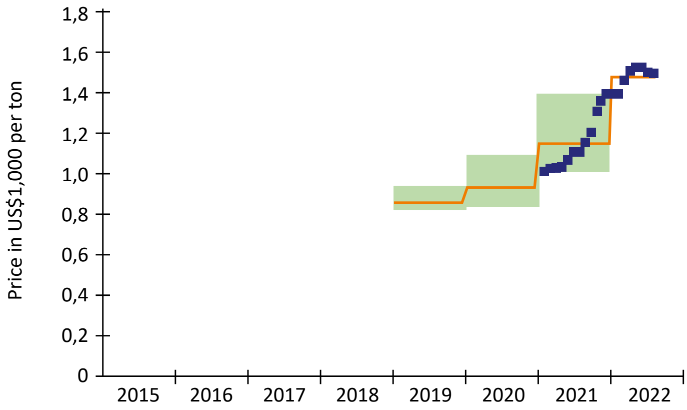
## Refining

**Countries with largest market shares**


**Relevant anode material manufacturers (capacity, 2020)**



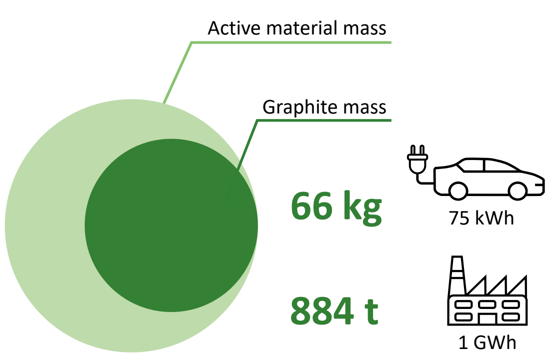

## Price monitor

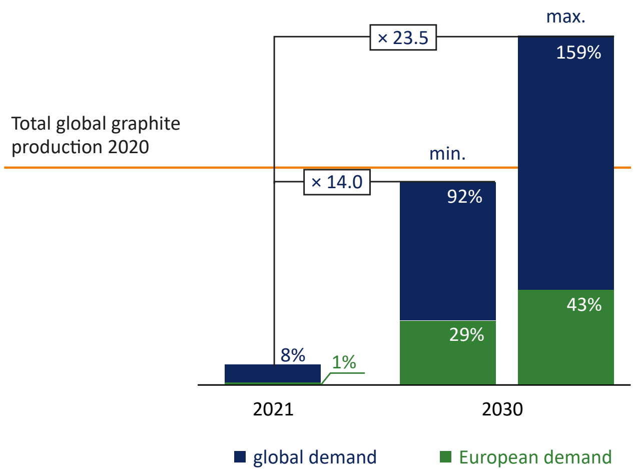



**Ø Sep 2021–Aug 2022:** 1,426
**Ø 2015–2021:** n/a

annual mean
min/max area
monthly mean

## Demand for battery cells




V Damm , S. (2021); Rohstoffrisikobewertung – Graphit. – DERA Rohstoffinformationen, 51: https://www.bgr.bund.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-51.pdf?__blob=publicationFile&v=4

# 3 COUNTRY AND MARKET CONCENTRATION IN MINING AND REFINING

Some raw materials such as nickel are mined and processed or refined in so many countries that the country concentration is only moderate. In contrast, the mining and refining of certain raw materials such as cobalt is concentrated in a small number of countries, so the country concentration is high. There are also raw materials that are mined in many countries but only processed in very few countries (e.g. manganese). A high concentration severely limits the options for diversification on the demand side, for example, to improve supply chain resilience or to comply with regulatory requirements (EU Supply Chain Law).

This section presents the **degree of country concentration and the WGI** in reference to the mining and refining volumes for the elements lithium, nickel, cobalt, manganese and graphite from the year 2020.[40] These characteristic values can be quantified and evaluated using the Herfindahl-Hirschman Index (HHI) and the weighted WGI[41,42], for both mining and refining (see info boxes). Based on these parameters, a risk assessment is carried out in the form of a risk portfolio with five categories. An explanation of the risk groups is also found in the appendix.

**Weighted WGI:**

The Worldwide Governance Indicators consist of six dimensions comprising 30 individual indicators. They indicate the perception of the quality of governance based on a large number of survey results. The data have been collected since 1996 and are provided by the World Bank.

The WGI for a country is the average of the six dimensions. A weighted WGI (e.g. for a group of goods) is the average of the product of the WGI and the country's share in the trade. Weighted or not, WGI values lie in the range of-2.5 to +2.5 and are assigned to five evaluation categories (-2.5 to-1.5 *very high*, > -1.5 to-0.5 *high*, >-0.5 to +0.5 *moderate*, > +0.5 to +1.5 *low*, > +1.5 to +2.5 *very low*).

For the most part, the examined raw materials are mined and refined outside the region under consideration (EU member states, EFTA member states and Great Britain). With the exception of manganese, small quantities in the international comparison are also mined and/or refined within the region under consideration. Significant refining capacities are only found for cobalt in the region under consideration. While there are large nickel refining capacities in the region under consideration, these are small in the international comparison.

### Country concentration higher for refining than for raw material extraction

Since raw material deposits are a prerequisite for extraction, the mining of raw materials is limited to countries with corresponding natural resources. Whether and to what extent raw materials are mined in the respective countries mainly depends on the economic aspects of mining (concentration of the raw material, accessibility etc.). These in turn are evaluated based on supply and demand. Unlike the mining of raw materials, refining is largely location-independent. Nevertheless, choosing the refining site also depends on economic aspects and on geopolitical decisions.

Nickel and manganese are mined in many countries and so the country concentration is moderate. The country concentration for lithium, cobalt and graphite mining is high. For refining on the other hand, the country concentration is high except for nickel. For manganese and graphite in particular, nearly or all of the refining takes place in just one country. Thus the country concentration for the refining of these raw materials is considerably higher compared to mining.

### Elevated weighted WGI for all raw materials

Only for lithium mining is the weighted WGI relatively low. The weighted WGI for nickel, manganese and graphite mining is moderate. For cobalt mining, the weighted WGI is relatively high. The weighted WGI for the refining of all the raw materials is moderate. Correspondingly the weighted WGI is lower for cobalt refining than mining. For lithium, the weighted WGI is higher for refining than for mining.

40 UK Critial Mineral Intelligence Centre, BRITISH GEOLOGICAL SURVEY CR/22/079: "Study on future UK demand and supply of lithium, nickel, cobalt, manganese and graphite for electric vehicle batteries"

41 The Worldwide Governance Indicators: Methodology and Analytical Issues by Daniel Kaufmann, Aart Kraay, Massimo Mastruzzi: SSRN [https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1682130] (Last accessed on: 12 December 2022)

42 http://info.worldbank.org/governance/wgi/ (Last accessed on: 12 December 2022)

**Herfindahl-Hirschman index:**

This indicator describes the market concentration. The sum of squares is calculated for all involved shares (in per cent). Thus the Herfindahl-Hirschman index (HHI) can have values from 0 to 10,000. There are three categories for evaluation: 0 to < 1,500 *low*, 1,500 to < 2,500 *moderate* and over 2,500 *high*.

This market concentration indicator goes back to Albert O. Hirschman (1945) and Orrin Herfindahl (1950).

**Asian companies dominate raw material refining**

Asian companies are among the world's largest producers for all the raw materials under consideration. Especially regarding the production of anode active material and the processing of manganese into electrolytic manganese metal or manganese sulphate, Asian manufacturers are highly dominant.

## 3.1 Lithium

With around 75% of the total extraction volume, **lithium is mainly mined** in Australia and Chile (see Figure 2, left). Further significant contributions to the total lithium extraction volume are made by China and Argentina. Lithium is also mined in the region under consideration. However, the volume mined in Portugal is so small in the international comparison that it is included under "Other" in Figure 2 (left). The country concentration for lithium mining is correspondingly high (HHI: 3,338) and the weighted WGI is low (0.91). The combination of the two indicators results in a low risk group of 2/5.

**Lithium refining** takes mostly place in China with approximately 58% of the total extraction (see Figure 2, right). Chile accounts for another significant share of global refining with about 30%. Considerably less lithium is refined in Argentina. Thus, the country concentration (HHI: 4,305) and weighted WGI (0.10) for refining are slightly higher than for mining. This process step is therefore assigned to risk group 3/5. The influence of refining companies based in China is apparent here. A selection of relevant companies with their lithium production capacity is presented in Figure 3. Aside from the Chinese companies, Albemarle and Livent refine lithium in China.

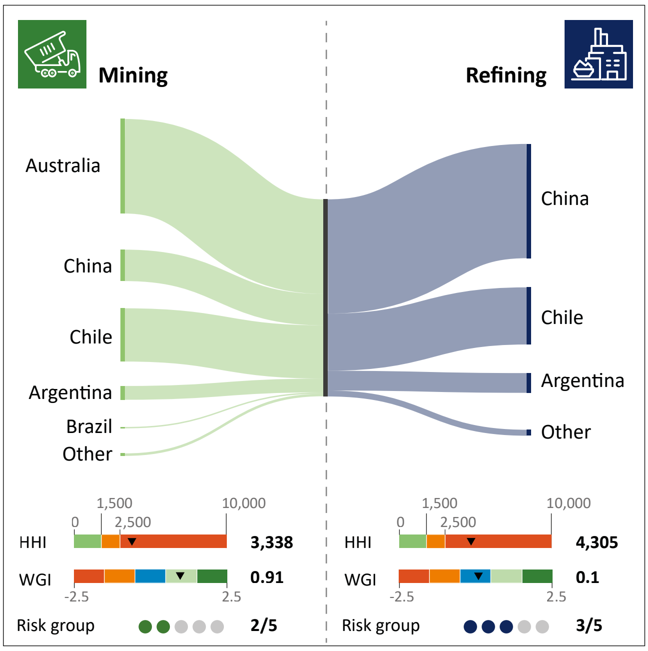



Figure 2: Sankey diagram for the raw material lithium with a total extraction volume of 85.8 kt content in 2020. It shows global extraction (left) (Australia 41.2 kt content, Chile 23.2 kt content, China 13.7 kt content, Argentina 6 kt content) and refining (right) (China 49.8 kt content, Chile 24.9 kt content, Argentina 8.6 kt content), proportionately by countries. In-house representation.


Figure 3: Selection of relevant lithium producers with their production capacity in 2020. In-house representation.

## 3.2 Nickel

**Nickel ore mining** with around 60% of the total extraction volume (2,580 kt content) largely happens in the Western Pacific region (Indonesia, Philippines, Australia and New Caledonia). The highest amount of nickel by far is mined in Indonesia. Many other mining countries contribute to the total global nickel extraction volume (see Figure 4, left). Nickel is also mined in Finland and other countries in the region under consideration. However, the amounts mined in Greece and Norway are so small in the international comparison that they are included under “Other” in Figure 4 (left). Since nickel is mined in many countries, the country concentration is moderate (HHI: 1,517). The weighted WGI is also moderate (0.18). The combination of the two indicators results in a low risk group of 2/5.

China is the leader in **nickel refining** with about 30% of the total extraction volume. Another significant share of global refining with around 25% goes to Indonesia (see Figure 4, right). Considerably less nickel is refined in countries such as Russia, Australia, Canada and Japan. Nickel is also refined in the region under consideration. However, the amounts refined in Finland, Great Britain or Greece, for example, are so low in the international comparison that they are included under “Other” in Figure 4 (right). Overall this results in a moderate country concentration (HHI: 1,605) that is only slightly higher than the index for mining. The weighted WGI is also assessed as moderate (0.11) and almost identical to the value for mining. This results in the risk group 2/5 for nickel refining. A selection of relevant nickel production companies is shown in Figure 5.

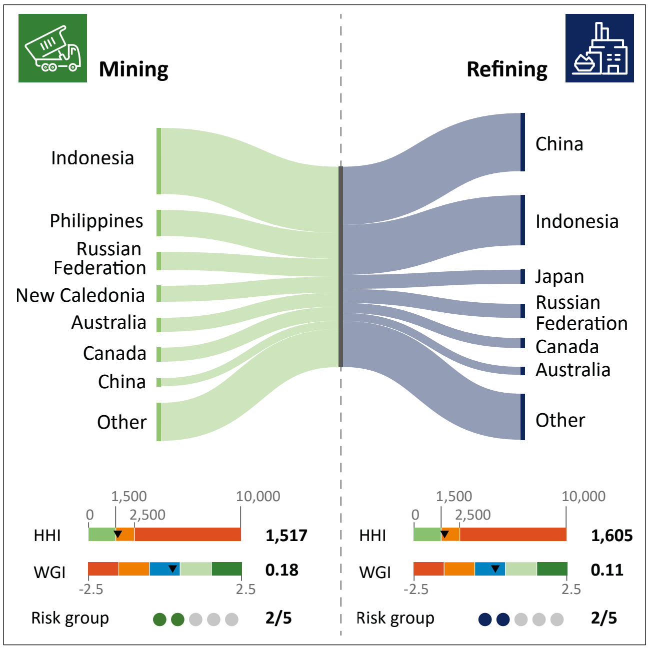



Figure 4: Sankey diagram for the raw material nickel with a total extraction volume of 2,580 kt content in 2020. It shows global extraction (left) (Indonesia 851.4 kt content, Philippines 335.4 kt content, Russian Federation 232.2 kt content, New Caledonia 206.4 kt content) and refining (right) (China 748.2 kt content, Indonesia 654 kt content, Russian Federation 180.6 kt content, Japan 180.6 kt content), proportionately by countries. In-house representation.

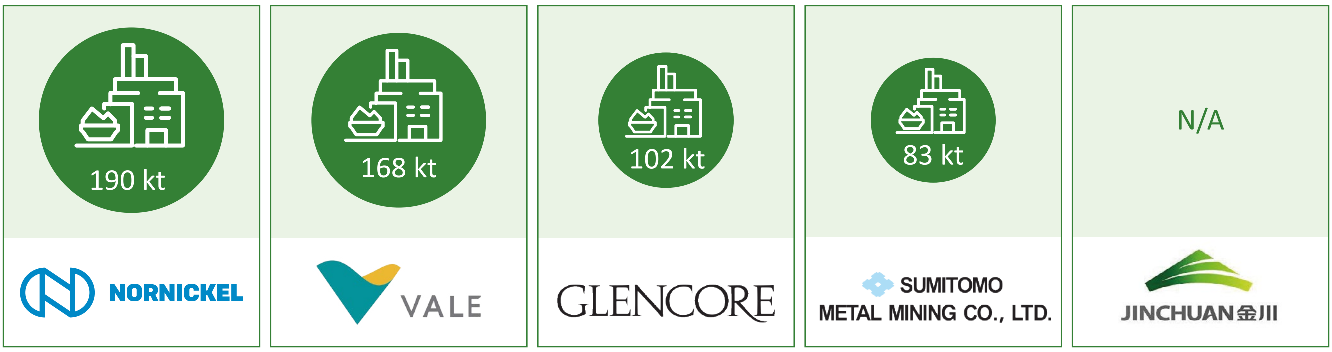



Figure 5: Selection of relevant nickel producers with their production volume in 2021. In-house representation.

## 3.3 Manganese

**Manganese is mainly mined** in South Africa with around 35% of the total manganese ore extraction volume of 47,500 kt (waste rock and ore) (see Figure 6, left). Australia and Gabon also make significant contributions to manganese mining with nearly 18% of the total extraction volume each. Many other mining countries contribute to the global manganese extraction volume. The country concentration for mining is therefore moderate (HHI: 1,624). The weighted WGI is also moderate (0.05). The combination of the two indicators results in a low risk group of 2/5.

More than 90% of **manganese refining** happens in China (see Figure 6, right). This results in a high country concentration (HHI: 8,649), much higher compared to manganese mining. Manganese refining is therefore assigned to the second-highest risk group (4/5) even though the weighted WGI as for mining is moderate (-0.25).

Figure 7 presents a selection of relevant companies with their production capacity for electrolytic manganese metal (EMM) and manganese sulphate monohydrate (MSM). One company clearly stands out with a very high capacity for electrolytic manganese metal production. Aside from the dominant Chinese companies, two companies are listed that produce EMM and/or MSM outside China. They are among the few producers not located in China. The market concentration is correspondingly high.

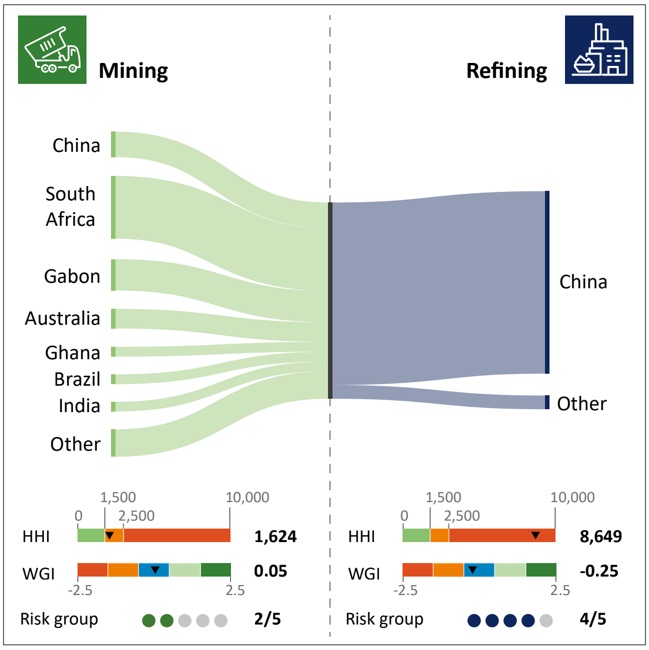



Figure 6: Sankey diagram for the raw material manganese with a total extraction volume of 47,500 kt in 2020. It shows global extraction (left) (South Africa 15,200 kt, Gabon 7,600 kt, China 6,175 kt, Australia 4750 kt) and refining (right) (China 44,175 kt), proportionately by countries. In-house representation.


Figure 7: Selection of relevant manganese producers with their production capacity. In-house representation.

## 3.4 Cobalt

With around 66% (97.7 kt content) of the total extraction volume (148 kt content), the Democratic Republic of the Congo is the leader in **cobalt mining** (see Figure 8, left). Several other countries are engaged in mining with significantly lower volumes. Cobalt is also mined in the region under consideration. However, the amount mined in Finland is so small in the international comparison that it is included under "Other" in Figure 8 (left). The country concentration for cobalt mining is therefore high (HHI: 4,422) and the weighted WGI is also high (-1.20). The combination of the two indicators results in a high risk group of 4/5.

China is the **cobalt refining** leader with about 65% of the total extraction volume (see Figure 8, right). Another significant proportion of global refining at around 20% falls to Finland, Belgium and Norway, countries in the region under consideration. Unlike mining, the weighted WGI for refining is therefore moderate (0.33). The country concentration, as for mining, is assessed as high (HHI: 4,441), that is why this process step is assigned to the moderate risk group 3/5.

A selection of relevant companies with their production volumes for cobalt or cobalt oxide is shown in Figure 9.

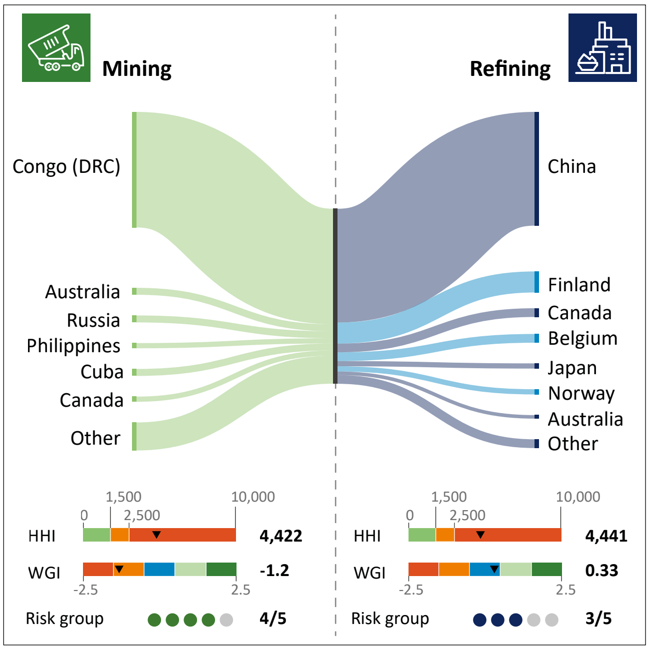



Figure 8: Sankey diagram for the raw material cobalt with a total extraction volume of 148 kt content in 2020. It shows global extraction (left) (Democratic Republic of the Congo 97.7 kt content, Russian Federation, Australia and Cuba respectively 5.9 kt content) and refining (right) (China 96.2 kt content, Finland 17.8 kt content, Belgium and Canada respectively 7.4 kt content), proportionately by countries. Processing in the region under consideration is shown by the dark shaded areas. In-house representation.


Figure 9: Selection of relevant cobalt producers with their production volumes in 2021. In-house representation.

## 3.5 Graphite

**Graphite mining** with around 68% (652 kt) of total production (959 kt) is located in China (see Figure 10). Other countries where natural graphite is mined include Brazil, Madagascar, South Korea and India. With a total extraction volume of around 200 kt, these countries however mine less than one-third of China's extraction volume. The country concentration for graphite mining is therefore high (HHI: 4,767). Graphite is also mined in the region under consideration. However, the volume mined in Norway is so small in the international comparison that it is included under "Other" in Figure 10. The weighted WGI is moderate (-0.23). The combination of the two indicators results in a moderate risk group of 3/5.

Since **refining** is also situated in China, it is hardly possible to differentiate between the companies engaged in graphite mining versus refining. Thus, it is not surprising that the WGI for refining with a value of-0.25 is of the same magnitude as the value for mining.

China also dominates the production of artificial graphite with over 50% of the global production volume. Other production countries include Japan and the USA. This results in a moderate weighted WGI (0.19) and a high country concentration (HHI: 3,187). For the production of artificial graphite, this leads to a moderate risk group of 3/5.

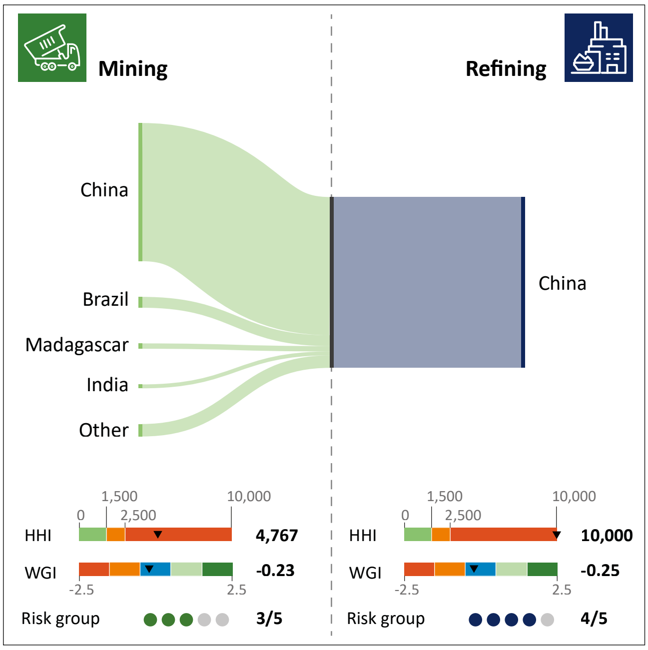



Figure 10: Sankey diagram for the raw material graphite with a total extraction volume of 959 kt in 2020. It shows global extraction (left) (China 652.1 kt, Brazil 95.9 kt, Madagascar 48 kt) and refining (right) (China 959 kt), proportionately by countries. In-house representation.

A selection of relevant companies with their production capacity for anode active material (AAM) from artificial and/or natural graphite is shown in Figure 11. AAM production is dominated by Chinese manufacturers. POSCO (South Korea) and Mitsubishi (Japan)[43] procure their natural graphite from China. The US Department of Energy published the report "America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition" in February 2022[44]. It notes the following: *"China also controls 100 percent of the processing of natural graphite used for battery anodes."*


Figure 11: Selection of relevant AAM producers with their production capacity in 2020. In-house representation.

43 https://www.mcgc.com/english/news_release/01281.html (Last accessed on: 12 December 2022)

44 America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition FINAL.docx_0.pdf (Last accessed on: 12 December 2022)

# 4 EUROPEAN VALUE CREATION

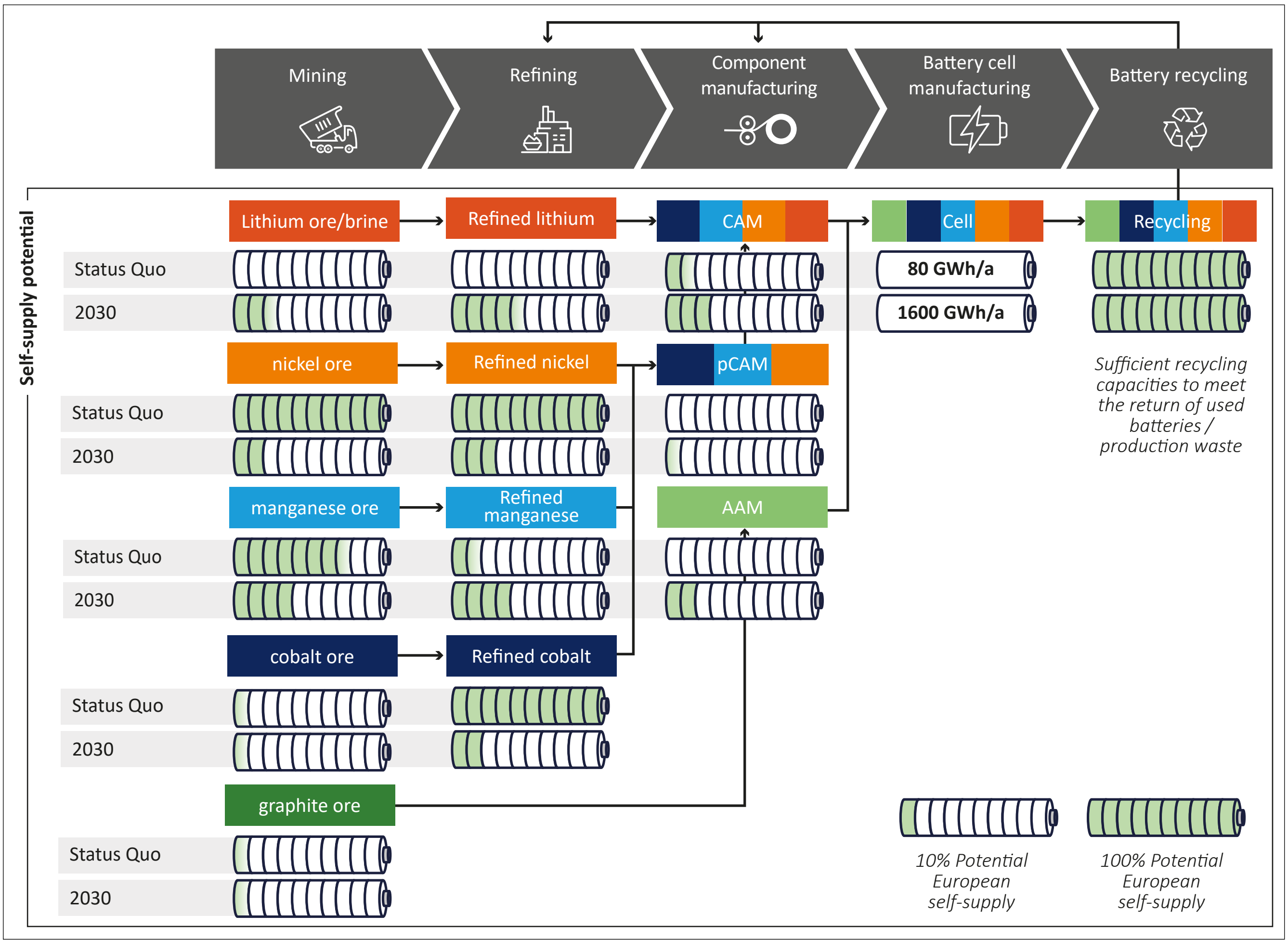



Figure 12: Examined value-added steps and raw material flows with presentation of the potential European self-supply. In-house representation

This section analyses the European battery value chain regarding a potential self-sufficiency. Aside from cell manufacturing, the value-added stages preceding cell manufacturing and recycling are examined. See Figure 12 and the corresponding info box for the key findings. Further information is found in the box “Methodology and information”.

Table 1: Key findings. In-house representation.

| Value-added steps | Status quo | 2030 |
|---|---|---|
|  | Of the five raw materials under consideration, nickel and manganese in particular are mined in larger quantities in Europe. The European nickel extraction volume would theoretically suffice to cover the demand of European cell manufacturing. However, most of the local nickel production goes to the steel industry and is not available to the battery industry. | The development of new nickel and cobalt deposits in Europe by 2030 is not foreseeable. New sites could be developed for lithium and manganese. The own supply of lithium could increase to around 25%. The potential own supply of manganese is expected to be around 45%. For natural graphite, the own supply may stagnate at about 5%. |
|  | Europe has capacities for nickel and cobalt refining. If these capacities were fully utilised for battery cell manufacturing, cell production in the region could be adequately supplied. Manganese refining to produce EMM or MSM is being realised on a smaller scale. Battery-quality lithium carbonate and lithium hydroxide are only being produced on a very small scale. | The own supply could increase to almost 45% for refined lithium and almost 40% for refined manganese. Expanding the capacities for the further processing of nickel and cobalt will not be able to keep pace with the expected growth of cell production capacities. The own supply could therefore fall to around 30% for nickel and around 20% for cobalt. |
|  | Only a few sites in Europe produce pCAM, CAM or AAM. A recently opened site in Poland is in the start-up phase and initially plans to supply up to 20 $GWh_{eq}$/a CAM. The remaining sites are mainly pilot plants with no concrete stated capacity. | Growth is expected for all three examined components within component manufacturing. The own supply could increase to around 30% for CAM and over 20% for AAM. Growth in pCAM production could be considerably lower, resulting in an own supply of less than 5%. |
|  | Currently the cell manufacturing capacity is around 80 GWh/a. | Projects that have been announced could increase the cell manufacturing capacity by a factor of 20 and reach 1600 GWh/a. |
|  | Currently the available plants in Europe can recycle about 12 $GWh_{eq}$/a of traction batteries. | The planned recycling capacities should be sufficient to process end-of-life traction batteries and production waste. Since the LIB service life for electric vehicles can exceed ten years, significant returns of end-of-life traction batteries are not expected before 2030. |

## Methodology and information

This section examines the potential Europe's own supply chain to cover the cell manufacturing demand for the five selected raw materials. To determine the potential own supply, relevant sites with products that can make a contribution to lithium-ion battery cell manufacturing were researched for each of the five value-added steps examined. Aside from considering the status quo, an outlook with possible developments until 2030 is provided based on site expansion and planned new sites.

All identified production capacities were converted to GWheq. For simplification, it was assumed that the status quo production capacities are used to manufacture LIBs with NMC-622 cathodes, and those in 2030 to manufacture LIBs with NMC-811 cathodes. Check the appendix for further information regarding conversion.

To determine the percentage of self-sufficiency, the calculated GWheq were divided by the calculated cell manufacturing capacity. The cell manufacturing capacity is 80 GWh for the status quo and 1600 GWh for 2030.

The potential own supply is a theoretical value based on the assumption that the examined products are fully dedicated to battery cell manufacturing. However, there is also demand for the examined materials from other industry sectors in the raw material extraction and material production value-added steps. This means they are not used exclusively for cell production in reality.

In general, please note that the potential own supply is an approximation. Exact forecasting is not possible since, for example, exact production capacities are not known for all of the sites that were researched. There are also no guarantees that all expansions and new sites can be realised as planned, or that all relevant European sites have been taken into account – diligent research notwithstanding.

The potential own supply therefore has to be viewed as an indicator of the value-added stages and products for which production facilities and know-how already exist in Europe, and of the value-added stages in which new facilities and new knowledge must be built and developed. Trends can also be derived from the results, indicating in which value-added steps significant growth is expected by 2030 and where there is a backlog.

## 4.1 Raw material extraction

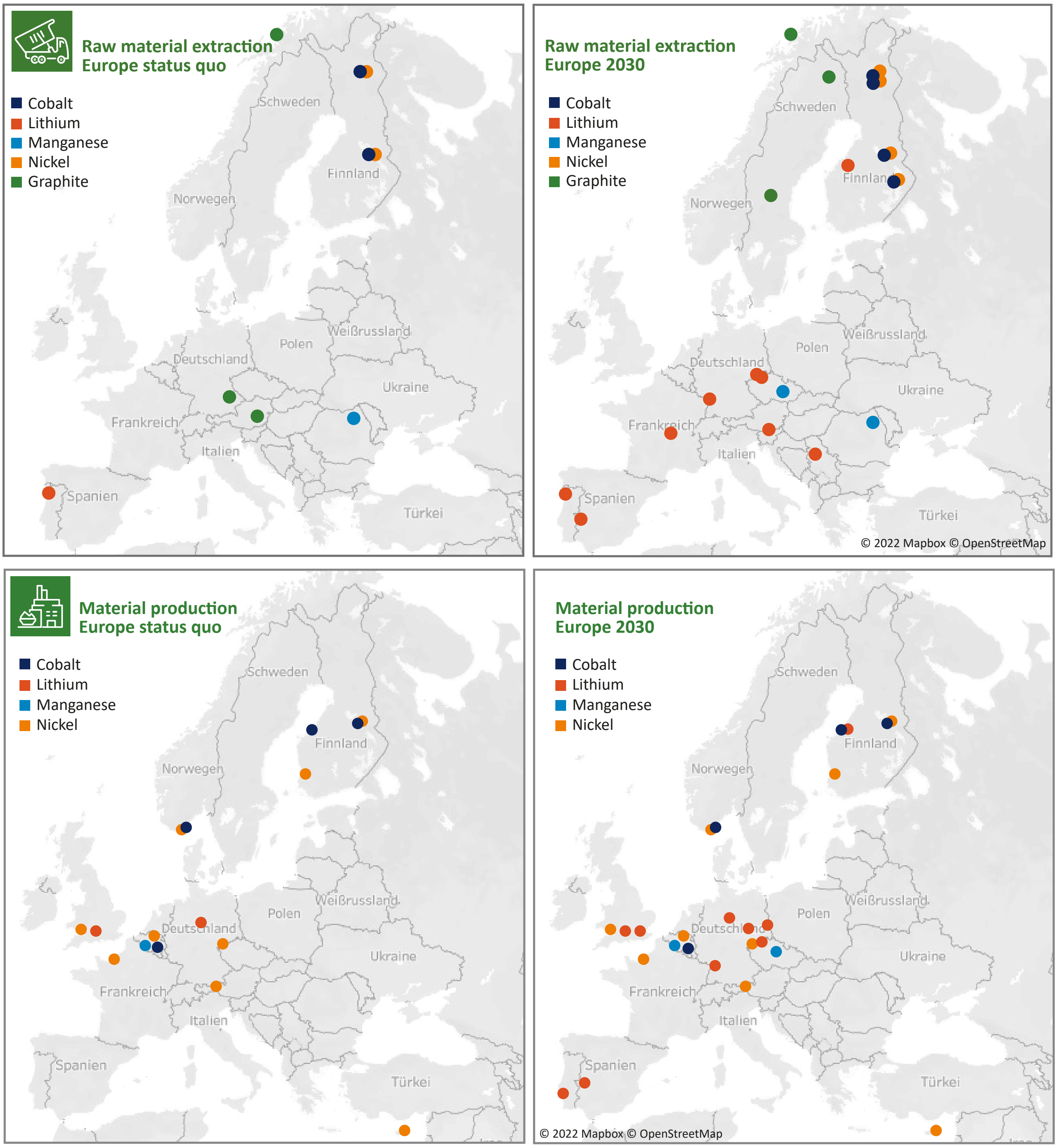



Figure 13: Mapping of all researched raw materials and material projects in Europe for this study (Last updated: December 2022)

All five of the examined raw materials are mined in Europe. Significant growth of the extraction capacities is expected by 2030, especially for lithium but also for manganese and natural graphite. The development of new deposits is not foreseeable for nickel and cobalt at this time.

Covering the demand of European cell production from local raw material deposits in 2030 will not be possible. Importing raw materials and/or processed precursors will be necessary, new mining sites notwithstanding. Reliable trade partners have to be found to ensure a secure supply.

### 4.1.1 Lithium ore/brine

As of 2022, there is no extraction of lithium for battery applications in Europe. Lithium is only mined in Portugal and used primarily for applications outside the battery industry (ceramics, for example).[45] There is no information on the production capacities.

The mapping shows that this situation will change by 2030. Numerous projects for the extraction of lithium are currently planned in Europe. Deposits have been discovered in Finland, Germany, the Czech Republic, Austria, Serbia, Portugal and Spain, among others. These could supply the European battery value chain with lithium. According to published production capacity information, around 425 $GWh_{eq}$/a could be realised with the planned extraction volumes by 2030. The own supply could increase to approximately 25% with the deposits that have been identified.

However, which projects can ultimately commence extraction and when remains to be seen. There were considerable protests in Serbia against the development of a lithium site that could make a significant contribution to the European supply with an annual capacity of around 100 $GWh_{eq}$. As a result of these protests, project development was suspended by politicians and mining licenses were retracted.[46] Protests against the development of raw material extraction projects are also happening in other European countries, such as Portugal.[47] This could lead to implementation delays. Realising raw material projects is generally a time-consuming process that can take ten years or more because of complex exploration phases, feasibility studies and approval procedures. Predicting the start of raw material projects is always subject to uncertainties due to the many influencing factors.

### 4.1.2 Nickel ore

Nickel is mined primary in Finland. If the identified Finnish nickel production were used to manufacture batteries with NMC-622 cathodes, more than 375 $GWh_{eq}$/a could be currently produced. This could theoretically cover the entire European demand.

Developing new nickel mining sites in Europe by 2030 is not foreseeable at this time. While there are potential sites where nickel deposits were discovered, exploring these sites is still in an early stage. For example, ores that in addition to copper could also contribute to the nickel supply could be mined at a new site in Finland. Production could still exceed 300 $GWh_{eq}$/a under the assumption that nickel production is kept at a comparable level until 2030 but that NMC-811 cathodes with a higher nickel content are used. The potential own supply would fall to around 20% in this case.

### 4.1.3 Manganese ore

The map of the status quo shows one manganese mining site in Romania. Aside from Romania, manganese is mined in continental Europe, in Ukraine among other countries. Ukraine mainly processes the manganese into ferromanganese or silicomanganese. Only a small proportion is turned into metallic manganese of low purity. Manganese extracted in Romania is mainly processed into ferromanganese or silicomanganese as well. Romania's manganese extraction volume would be sufficient for nearly 60 $GWh_{eq}$/a based on NMC-622 cathode material. This extraction volume could theoretically cover 75% of the own demand.

A manganese deposit to be used explicitly for battery material production is to be developed in the Czech Republic by 2030. Plans are to not only mine the manganese but to turn it directly into high-purity EMM/MSM. With the existing deposits in Romania and the capacities planned there, more than 750 $GWh_{eq}$/a of NMC-811 cathode material could be produced by 2030. Thus, the theoretical own supply could be around 45%.

### 4.1.4 Cobalt ore

Cobalt is only mined in small quantities in Europe. It is extracted as a by-product of some operations in Finland. Currently the extraction volume would be sufficient for battery capacities of about 3 $GWh_{eq}$/a. The potential own supply for this raw material is therefore less than one per cent.

Developing new cobalt deposits by 2030 is not foreseeable. While new sites are being explored, these explorations are still in a very early stage. The feasibility of these sites is questionable and the start of production cannot be estimated. Based on the scenario described at the start of this section that the proportion of nickel in LIBs will fall and the proportion of cobalt is going to increase, more than 6 $GWh_{eq}$/a could be produced with European cobalt extraction by 2030. The own European supply would thus remain below one per cent.

45 Metals for Clean Energy: Pathways to solving Europe's raw materials challenge (Last accessed on: 12 December 2022)

46 https://www.reuters.com/business/rio-tinto-keen-restart-talks-stalled-serbian-lithium-project-2022-05-05/ (Last accessed on: 12 December 2022)

47 https://www.reuters.com/business/environment/europes-green-deal-needs-get-round-anti-mining-roadblock-andy-home-2021-12-16/ (Last accessed on: 12 December 2022)

### 4.1.5 Graphite ore

Aside from small operations in Germany and Austria, natural graphite is mined in Europe at sites in Ukraine and Norway among others. The extraction volumes of the Norwegian site would currently suffice for about 5 $GWh_{eq}$/a. This could theoretically cover nearly 5% of the own European demand.

The Norwegian site is to be expanded going forward, supplying graphite for AAM production in Norway. A new graphite deposit is also being developed in Sweden. Graphite for battery applications could be mined there starting in 2025. A production facility for AAM is being constructed at the same time (see component manufacturing 2030). There is another graphite mine in Sweden that has currently stopped production for economic reasons. Operating this mine economically may be possible again in view of current market and price dynamics due to the high demand for AAM. A comparatively fast return to production is possible thanks to the existing infrastructure. Natural graphite for more than 100 $GWh_{eq}$/a could be extracted in Europe by 2030 with the projects that have been announced. The potential own supply could therefore stagnate at around 5%.

## 4.2 Material production

The European capacities for processing nickel and cobalt are greater than the European raw material deposits. Suitable precursors therefore have to be imported to fully utilise the facilities. Some of the refining operations run their own mining sites or have the necessary access rights to safeguard their supply of the required base material. Lithium refining capacities are expected to be nearly double the capacities of the European lithium raw material sources by 2030. As with nickel and cobalt, some companies have direct access to raw material sources outside Europe to safeguard their basic supply. However, additional base material needs to be procured through the commodity markets for full capacity utilisation. Reliable partnerships are therefore a basic prerequisite for supply security.

### 4.2.1 Lithium precursors

Currently there are few sites in Europe that process significant quantities of lithium into lithium carbonate or lithium hydroxide for battery applications. Two sites where lithium is processed into lithium carbonate or lithium hydroxide are shown in the map of the status quo. While there are two other sites in Europe where lithium is processed, it is not clear whether they also produce lithium carbonate or lithium hydroxide for battery applications. Therefore, they are not shown on the map.

New processing facilities are to be constructed by 2030. Aside from processing facilities planned in the vicinity of potential mining sites, to be supplied by them, there are processing facilities that are not directly connected to European mining sites. These processing facilities in part plan to access mining sites owned by the same companies outside Europe – in Brazil or Canada, for example – to safeguard their basic lithium supply. Companies with no direct access to mining sites have to obtain suitable input material through the commodities market. Supply shortages and therefore bottlenecks in the supply to refineries are possible due to the very high demand. At more than 700 $GWh_{eq}$/a, the potential refining capacity is double the potential extraction volume. Importing lithium precursors is therefore essential to utilise plant capacities. With full capacity utilisation, the announced lithium refineries could cover about 45% of the announced cell manufacturing capacity by 2030.

### 4.2.2 Nickel precursors

Nickel is processed in Scandinavia, Great Britain, France, Belgium, Germany and Austria among others. Refining capacities at more than 725 $GWh_{eq}$/a are nearly double the identified European extraction volumes. European processing sites therefore depend on a supply from raw material sources outside Europe. To safeguard this supply, refinery operators are generally active in raw material extraction as well and have direct access to raw material sources outside Europe. Due to their proximity to seaports, nickel refineries generally have good international sea transport connections. The sites shown on the map for nickel processing in Central Europe primarily focus on scrap processing. Theoretically the refining capacities would be more than sufficient to cover the current demand for European cell manufacturing.

The nickel demand for LIBs will increase by 2030. Companies in Germany, France, Finland and Cyprus among others have announced production capacity increases to meet this demand. In spite of the announced expansion, significantly higher $GWh_{eq}$/a production in Europe by 2030 is not foreseeable since the demand for nickel increases based on the assumption that NMC-811 cathode material will be used in 2030.

### 4.2.3 Manganese precursors

Manganese is currently being processed into EMM or MSM of battery quality for use in LIBs in Belgium. The capacities could suffice for around 12 $GWh_{eq}$/a NMC-622 CAM. An own supply of more than 15% could thus be obtained. European manganese ore production would be theoretically sufficient to meet this demand. Suitable input material does however need to be imported since these extraction volumes are used for the production of alloys.

Manganese in battery quality for more than 600 $GWh_{eq}$/a NMC-811 could be produced by 2030 thanks to planned manganese mining in the Czech Republic and the connected processing facility. The potential own supply could increase to nearly 40%.

### 4.2.4 Cobalt precursors

There are processing facilities for cobalt in Norway, Belgium and especially Finland. These sites have to be supplied through imports since raw material deposits in Europe are limited. Cobalt for around 110 $GWh_{eq}$/a can be processed at these sites today. This could theoretically more than cover the demand for European cell manufacturing.

Refining capacities are to be in part expanded by 2030. Based on the assumption that the demand for cobalt will fall going forward due to high-nickel cathode material, more than 325 $GWh_{eq}$/a of NMC-811 could be produced with the projected refining capacities by 2030. The potential own supply would fall to about 20%.

### 4.2.5 Graphite precursors

Examining sites where natural graphite is processed into a precursor for AAM production is outside the scope of this study. Graphite as a raw material is therefore not analysed in this section. Sites for the production of AAM are analysed in the component manufacturing section.

**Excursus: trade data**

95 intermediate products along the value chain from the raw material to the precursors for battery cell manufacturing were identified in this study for the most common cell technologies – NMC, NCA and LF(M)P (see Figure 1). Since the refining operations in the region under consideration depend on raw material imports, trade groups[48] for the elements lithium, nickel, manganese, cobalt and graphite examined in this study were researched using Trade Map, starting with the countries where they are mined (see Section 3). All trade groups comprising the intermediate products relevant for battery cell manufacturing from the raw material (ores) to raffinates were analysed regarding the global export volumes and the quantities imported into the region under consideration. It turns out that most of the examined trade relations exhibit a low to moderate weighted WGI. One thing that stands out is that the WGI for imports into the region under consideration is higher in several cases compared to global exports. Regarding the country concentration, note that this is generally high, with few exceptions, and that imports into the region under consideration usually exhibit a higher country concentration compared to global exports.

In the overall view of all raw materials that were evaluated, both global exports and imports into the region under consideration are assigned to the moderate risk group (2.75/2.67 out of 5). Regarding imports into the region under consideration, all examined nickel product groups and cobalt powder are in the lowest risk group (1/5 and 2/5). The product groups “manganese and its products” and natural graphite (HS 250490) are assigned to the second-highest risk group (4/5). All other product groups that were examined are in the moderate risk group 3/5.

***Lithium***

Global exports of **lithium carbonate** (HS 283691) are limited to a few countries of origin. This results in a high country concentration (HHI: 5,581). The weighted WGI of the export countries is low (0.67). According to the combined view, global exports of lithium carbonate are in the low risk group (2/5).

Imports of lithium carbonate into the region under consideration accounted for about 12% of total global exports in 2020. As shown in Figure 14 (blue circle), imports into the region under consideration are less diverse than global exports. The country concentration is correspondingly higher (HHI: 7,414). However, imports come from countries with a lower average WGI (weighted WGI: 0.77). Nevertheless, the higher country concentration results in a moderate risk for lithium carbonate imports into the

48 A description of the underlying data is provided in the appendix

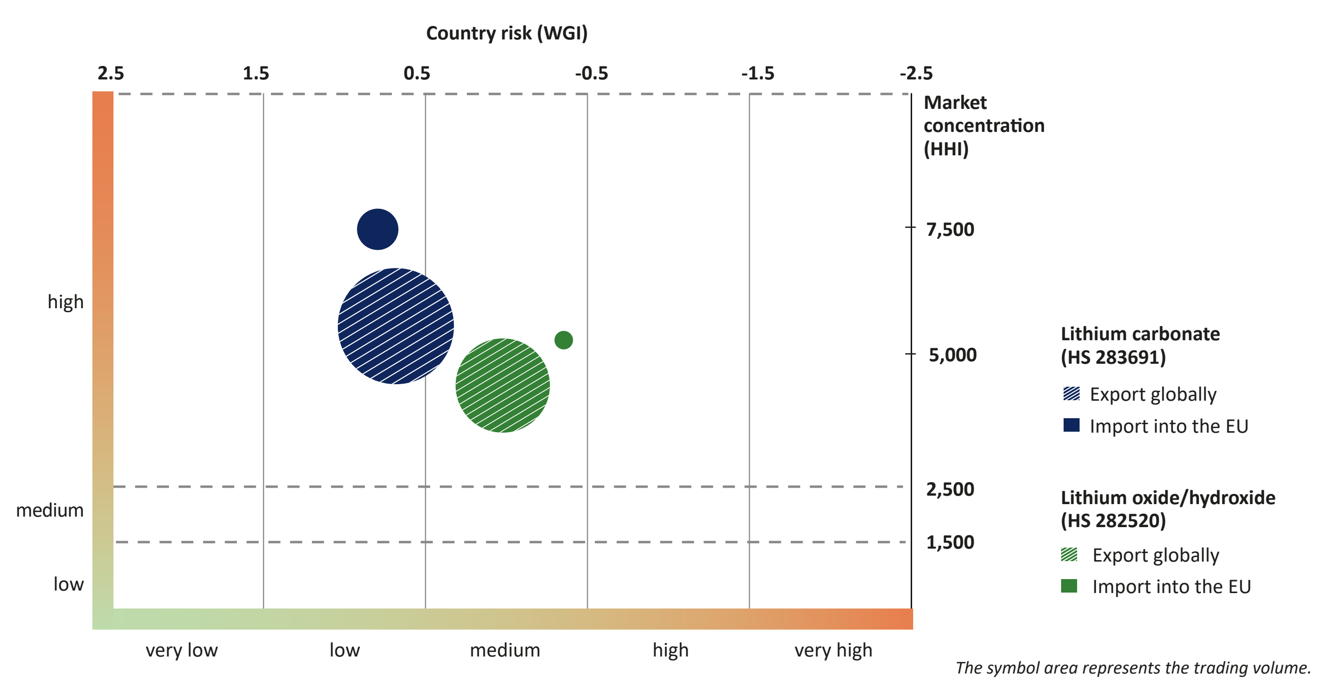



Figure 14: Localisation of trade volumes for lithium carbonate (blue, HS 283691) and lithium oxide/hydroxide (green, HS 282520) according to their weighted WGI (X-axis) and the Herfindahl-Hirschman index (Y-axis). Shaded circles: World trade volumes for lithium carbonate (144 kt) and lithium oxide/hydroxide (88 kt). Solid circles: Imports of lithium carbonate (17.5 kt) and lithium oxide/hydroxide (3.5 kt) into the region under consideration. In-house representation.

region under consideration (risk group 3/5). This is a higher risk group compared to global exports. The supply chain therefore appears less stable against disruptions than global trade because the export countries are not as diverse.

Global exports of **lithium oxide/hydroxide** (HS 282520) come from a small number of countries, resulting in a high country concentration (HHI: 4,499). The weighted WGI of the export countries is moderate (0.01). According to the combined view, global exports of lithium oxide/hydroxide are in the moderate risk group (3/5).

Imports into the region under consideration accounted for just 4% of total global exports in 2020. Compared to global exports, both the country concentration (HHI: 5,285) and the weighted WGI (-0.38) are higher for imports (see Figure 14, green circle). Corresponding to the high country concentration and moderate WGI, lithium oxide/hydroxide imports are in the moderate risk group (3/5). However, imports into the region under consideration must be assessed as more critical than global exports and the existing global supply chains offer the option of diversifying imports and reducing the risk of the export countries.

***Nickel***

Global exports of **raw nickel** (HS 750210) are divided among numerous countries of origin, resulting in a moderate country concentration (HHI: 1,680). The weighted WGI of the export countries is low (0.84). According to the combined view, global exports of raw nickel are in the very low risk group (1/5).

Imports of raw nickel into the region under consideration accounted for about 20% of global exports in 2020. As shown in Figure 15 (green circle), imports into the region under consideration come from fewer countries than global exports. The country concentration is assessed as high (HHI: 3,071). The countries of origin also exhibit an elevated weighted WGI (0.35). Raw nickel imports are therefore assigned to the moderate risk group (3/5), a higher risk group compared to global exports. The existing global supply chains therefore offer the option of diversifying imports and reducing the risk of the export countries.

Global exports of **nickel matte** (HS 750110) come from many countries, resulting in a moderate country concentration (HHI: 2,601). The weighted WGI of the export countries is low (0.51). According to the combined view, global exports of nickel matte are in the low risk group (2/5).

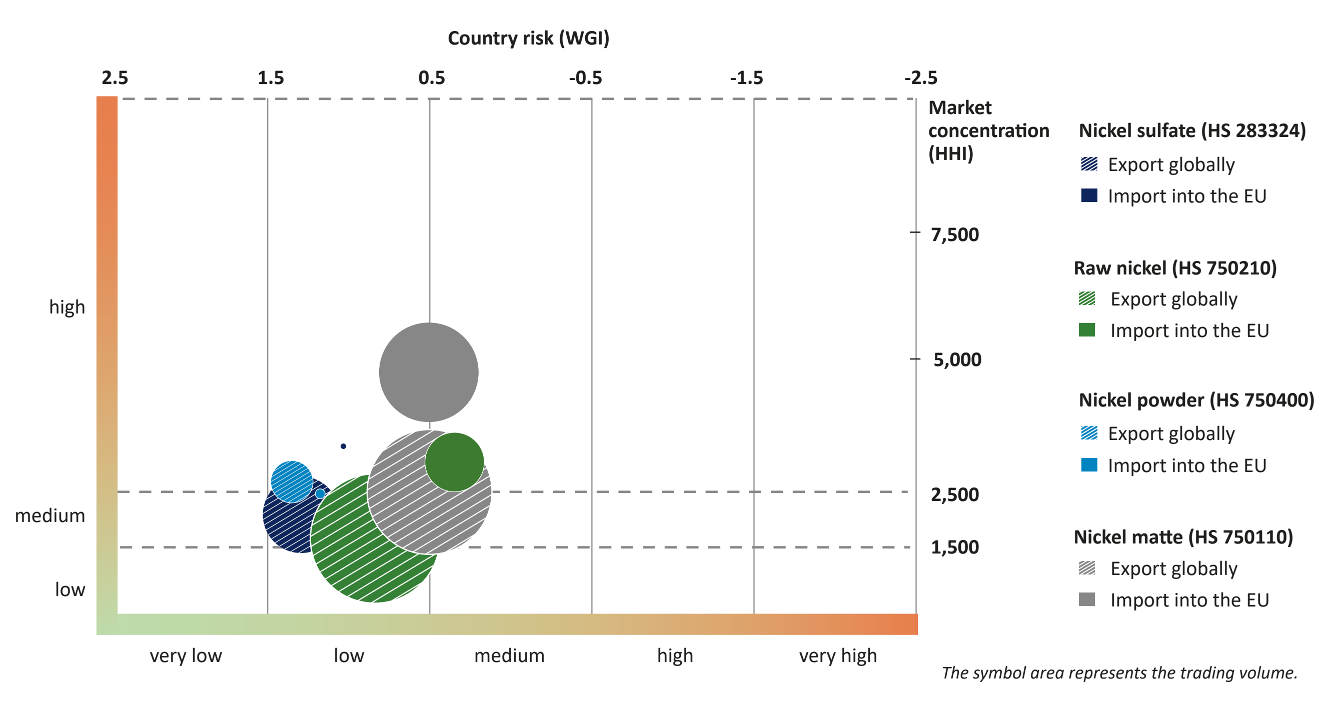



Figure 15: Localisation of trade volumes for nickel sulphate (blue, HS 283324) raw nickel (green, HS 750210), nickel powder (light blue, HS 750400) and nickel matte (grey, HS 750110) according to their weighted WGI (X-axis) and the Herfindahl-Hirschman index (Y-axis). Shaded circles: World trade volumes for nickel sulphate (169 kt), raw nickel (477 kt), nickel powder (49 kt), nickel matte (431 kt). Solid circles: Imports into the region under consideration for nickel sulphate (0.85 kt), raw nickel (97 kt), nickel powder (2.7 kt), nickel matte (273 kt). In-house representation.

Imports of nickel matte into the region under consideration accounted for about 63% of global exports in 2020. They mainly came from two countries (Canada and the Russian Federation). Compared to global exports, the country concentration (HHI: 4,795) is therefore considerably higher (see Figure 15, grey circle). The weighted WGI for imports is at the level for exports (0.5). Corresponding to the high country concentration and low WGI, nickel matte imports are also assigned to the low risk group (2/5). However, imports into the region under consideration must be assessed as more critical than global exports and the existing global supply chains offer the option of diversifying imports.

Global exports of **nickel sulphate** (HS 283324) are distributed among numerous countries of origin, resulting in a moderate country concentration (HHI: 2,050). The weighted WGI of the export countries is low (1.29). According to the combined view, global exports of raw nickel are in the very low risk group (1/5).

Nickel sulphate imports into the region under consideration accounted for about 0.5% of global exports in 2020. As shown in Figure 15 (blue circle), imports into the region under consideration came from fewer countries than global exports. The country concentration is assessed as high (HHI: 3,367). The countries of origin also exhibit a higher weighted WGI (1.03). Nickel sulphate imports are therefore in the low risk group (2/5), a higher risk group compared to global exports. The existing global supply chains therefore offer the option of diversifying imports and reducing the risk of the export countries.

***Manganese***

Figure 16 (blue circle) shows that global exports of the product group "manganese and articles thereof" (HS 811100) are limited to a few countries of origin and accordingly highly concentrated (HHI: 7,024). The weighted WGI of the export countries is moderate (0.09). According to the combined view, global exports are in the second-highest risk group (4/5).

Imports of **"manganese and articles thereof"** into the region under consideration accounted for about 20% of total global exports in 2020. Compared to global exports, both the country concentration (HHI: 7,829) and the weighted WGI (-0.27) are somewhat higher for imports. Corresponding to the high country concentration and moderate WGI, imports of "manganese and articles thereof" are assigned to the second-highest risk group (4/5). However, imports into the region under consideration must be assessed as somewhat more critical than global exports. The existing global supply chains offer the option of diversifying imports and reducing the risk of the export countries.

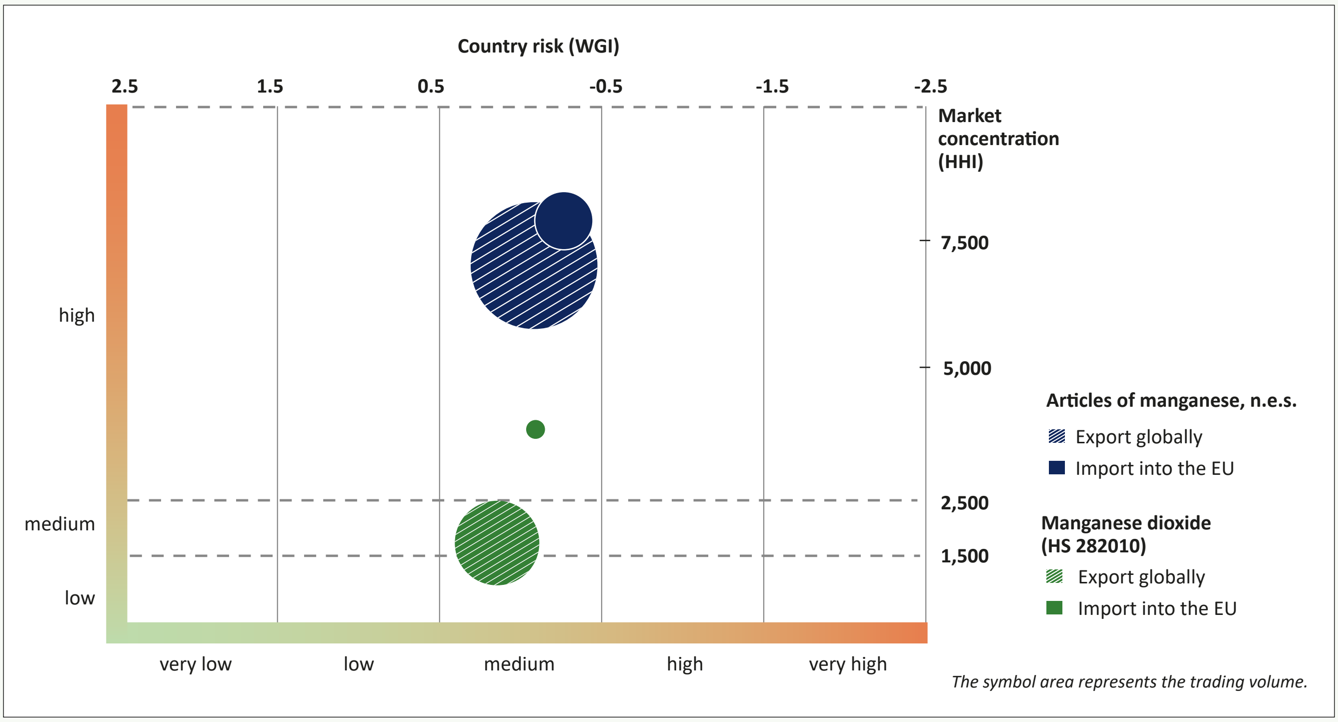



Figure 16: Localisation of trade volumes for "manganese and articles thereof" (blue, HS 811100) and manganese oxide (green, HS 282010) according to their weighted WGI (X-axis) and the Herfindahl-Hirschman index (Y-axis). Shaded circles: World trade volume for manganese and articles thereof (444 kt), manganese oxide (196 kt). Solid circles: Imports into the region under consideration for manganese and articles thereof (90 kt), manganese oxide (9.5 kt). In-house representation.

Global exports of **manganese dioxide** (HS 282010) come from many countries, resulting in a moderate country concentration (HHI: 1,724). The weighted WGI of the export countries is low (0.15). According to the combined view, global exports of manganese dioxide are in the low risk group (2/5).

Imports of manganese dioxide into the region under consideration accounted for about 4.8% of global exports in 2020. They came from significantly fewer than the total number of export countries. Compared to global exports, the country concentration (HHI: 3,857) is therefore considerably higher (see Figure 16, green circle). The weighted WGI for imports is slightly higher compared to exports (-0.09). Corresponding to the high country concentration and moderate WGI, manganese dioxide imports are assigned to the moderate risk group (3/5). This is a higher risk group compared to global exports. The existing global supply chains therefore offer the option of diversifying imports and reducing the risk of the export countries.

***Cobalt***

Global exports of **cobalt oxide/hydroxide** (HS 282200) are divided between numerous countries of origin, resulting in a moderate country concentration (HHI: 2,200). The weighted WGI of the export countries is moderate (-0.11). According to the combined view, global exports of cobalt oxide/hydroxide are in the low risk group (2/5).

Imports of cobalt oxide/hydroxide into the region under consideration accounted for about 5% of total global exports in 2020. They came from significantly fewer than the total number of export countries. Compared to global exports, the country concentration (HHI: 5,084) is therefore considerably higher (see Figure 17, green circle). The weighted WGI for imports is slightly higher compared to exports (-0.41). Corresponding to the high country concentration and moderate WGI, cobalt oxide/hydroxide imports are assigned to the moderate risk group (3/5). This is a higher risk group compared to global exports. The existing global supply chains therefore offer the option of diversifying imports and reducing the risk of the export countries.

Figure 17 (blue circle) shows that global exports of **cobalt powder** (HS 810520) are limited to a few countries of origin and therefore highly concentrated (HHI: 7,353). The weighted WGI of the export countries is high (-1.24). According to the combined view, global exports are in the highest risk group (4/5).

Imports of cobalt powder into the region under consideration accounted for about 4% of total global exports in 2020. Compared to global exports, both the country concentration

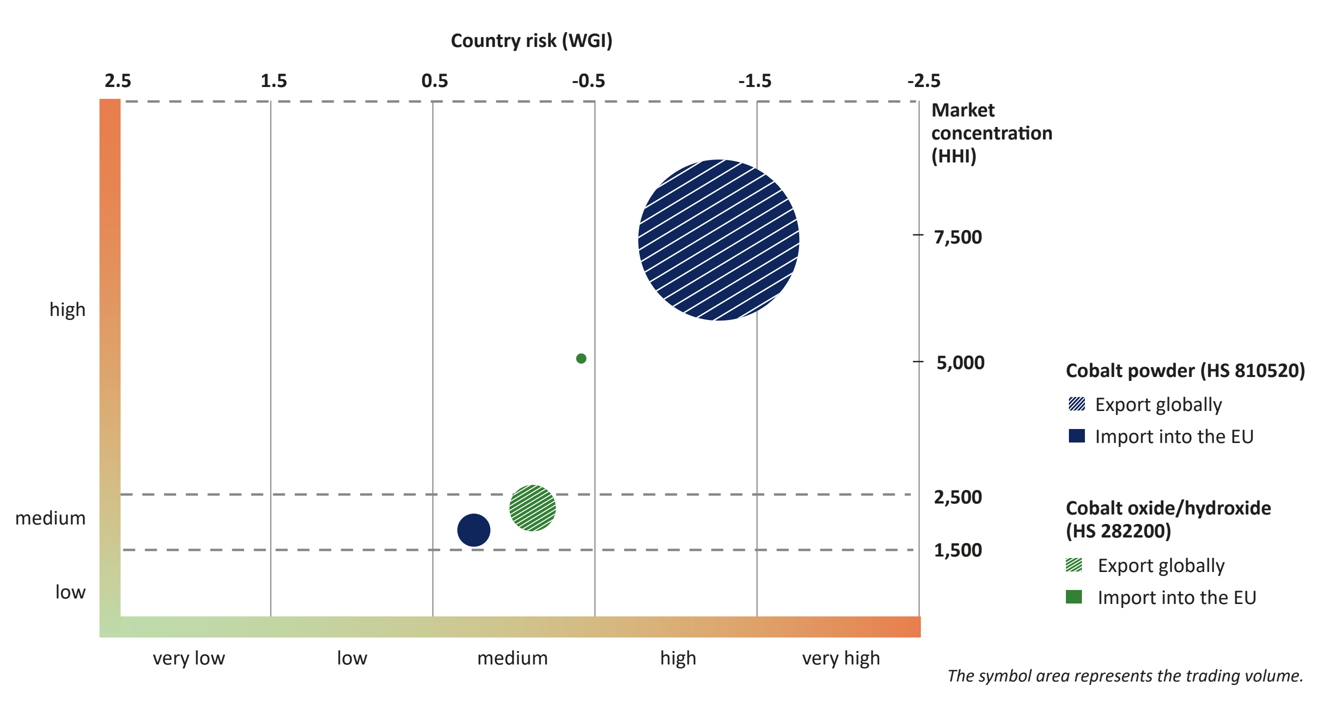



Figure 17: Localisation of trade volumes for cobalt oxide/hydroxide (blue, HS 810520) and cobalt powder (green, HS 282200) according to their weighted WGI (X-axis) and the Herfindahl-Hirschman index (Y-axis). Shaded circles: World trade volume for cobalt powder (353 kt) and cobalt oxide/hydroxide (28 kt). Solid circles: Imports of cobalt powder (14.5 kt) and cobalt oxide/hydroxide (1.4 kt) into the region under consideration. In-house representation.

(HHI: 1,832) and the weighted WGI (0.25) are considerably lower for imports. Corresponding to the moderate country concentration and moderate WGI, cobalt powder imports are assigned to the low risk group (2/5). This is a lower risk group compared to global exports. The existing global supply chains therefore offer few options for diversifying imports and reducing the risk of the export countries.

***Graphite***

Graphite is traded in three forms: Natural as powder and flakes (HS 250410), natural except powder or flakes (HS 250490) and artificial (HS 380110).

Global exports of **natural graphite as powder and flakes** (HS 250410) come from several countries, resulting in a high country concentration (HHI: 2,954). The weighted WGI of the export countries is moderate (0.02). According to the combined view, global exports of natural graphite as powder and flakes are in the moderate risk group (3/5).

Imports of natural graphite as powder and flakes into the region under consideration accounted for about 20% of total global exports in 2020. Compared to global exports, the country concentration is slightly lower for imports (HHI: 2,647) and the weighted WGI (0.37) is slightly higher. Corresponding to the high country concentration and moderate WGI, imports of natural graphite as powder and flakes are in the moderate risk group (3/5). However, imports into the region under consideration must be assessed as somewhat more critical than global exports. The existing global supply chains offer few options for diversifying imports and reducing the risk of the export countries.

Global exports of **natural graphite except powder or flakes** (HS 250490) are limited to a few countries, resulting in a high country concentration (HHI: 8,354). The weighted WGI of the export countries is low (0.89). According to the combined view, global exports of natural graphite as powder and flakes are in the moderate risk group (3/5).

Imports of natural graphite except powder or flakes into the region under consideration accounted for about 0.1% of total global exports in 2020. Compared to global exports, the country concentration is slightly lower for imports (HHI: 6,629) and the weighted WGI (0.23) is considerably higher. Corresponding to the high country concentration and moderate WGI, imports of natural graphite except powder or flakes are in the second-highest risk group (4/5). This is a higher risk group compared to global exports. The existing global supply chains therefore offer the option of diversifying imports and reducing the risk of the export countries.

Global exports of **artificial graphite** (HS 380110) come from several countries, resulting in a high country concentration (HHI: 6,027). The weighted WGI of the export countries is moderate (-0.01). According to the combined view, global

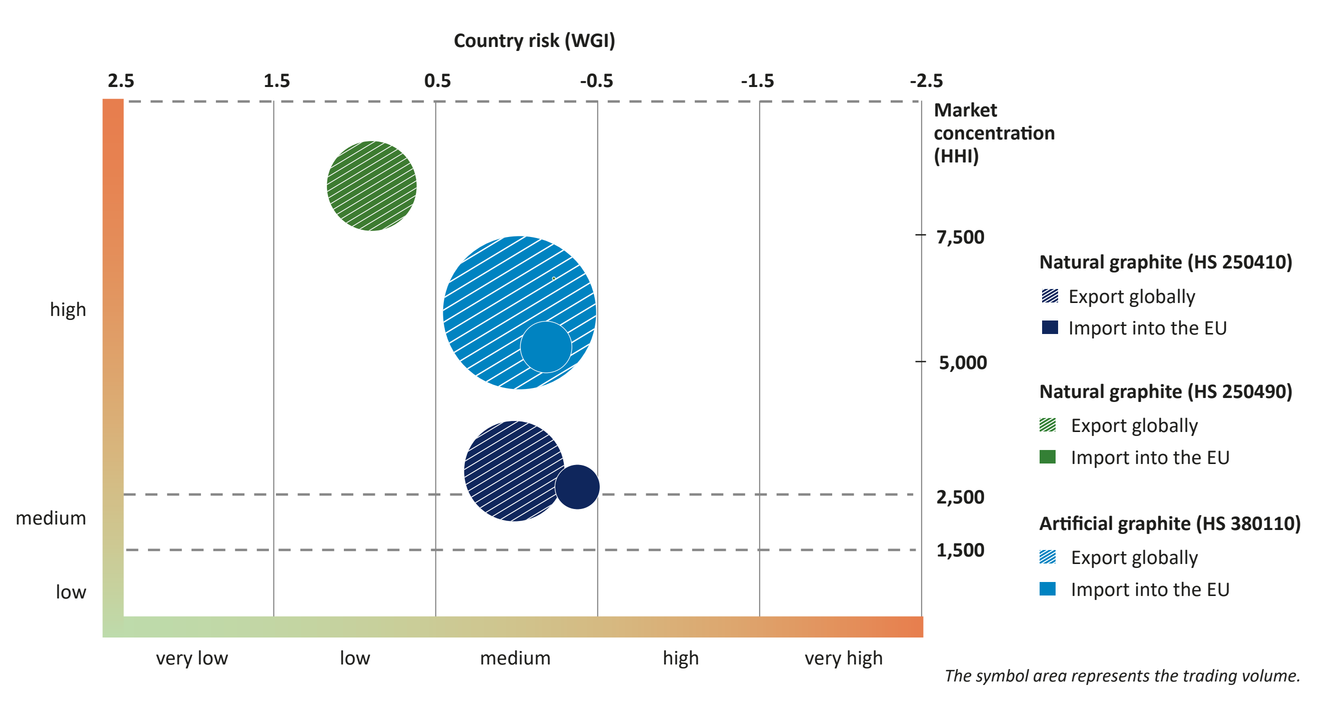



Figure 18: Localisation of trade volumes for graphite – natural powder and flakes (blue, HS 250410), natural except powder or flakes (green, HS 250490) and artificial (turquoise, HS 380110) – according to their weighted WGI (X-axis) and the Herfindahl-Hirschman index (Y-axis). Shaded circles: World trade volume for natural graphite HS 250410 (347 kt), natural graphite HS 250490 (284 kt), artificial graphite (793 kt). Solid circles: Imports into the region under consideration for natural graphite HS 250410 (69 kt), natural graphite HS 250490 (0.3 kt), artificial graphite (90.6 kt). In-house representation.

exports of natural graphite as powder and flakes are in the moderate risk group (3/5).

Imports of artificial graphite into the region under consideration accounted for about 11% of total global exports in 2020. Compared to global exports, the country concentration is slightly lower for imports (HHI: 5,346) and the weighted WGI (0.17) is slightly higher. Corresponding to the high country concentration and moderate WGI, imports of artificial graphite are in the moderate risk group (3/5). However, imports into the region under consideration must be assessed as somewhat more critical than global exports. The existing global supply chains offer few options for diversifying imports and reducing the risk of the export countries.

## 4.3 Component manufacturing

Europe currently has low component manufacturing capacities. Production capacities in Europe are to be expanded considerably by 2030. According to the current state of knowledge, these capacities will however be insufficient to cover the battery cell manufacturing demand. Europe will therefore depend on imports of active material and precursor material in the future. For precursors in particular, there is a great capacity deficit compared to CAM production and battery cell manufacturing. It is by all means possible that some CAM sites also have production lines to manufacture pCAM, so that the deficit can be reduced. Critical dependencies can nevertheless arise here if the supply of input materials essential for production is not assured.

Announcements of sites for manufacturing battery components in Scandinavia illustrate that region's ambitions to further develop the battery value chain and actively take part in the European battery ecosystem.

### 4.3.1 Precursors for cathode active material

No sites producing precursors for cathode active material (pCAM) are currently known in Europe.

Two sites are planned in Finland which stated to produce more than 40 $GWh_{eq}$/a by 2030. They could cover 2.5% of the projected demand by 2030. pCAM production may also take place directly at planned CAM production sites. This would further increase the self-sufficiency.

### 4.3.2 Cathode active material

Cathode active material (CAM) is produced in Germany and Poland among other countries. The identified site in Germany operates a pilot plant with a comparatively low capacity. The plant in Poland will be able to supply CAM for up to 20 $GWh_{eq}$/a in the near future.

Sites in Germany and Poland are to be considerably expanded in part by 2030. New sites and expansions have also been announced in Poland, Finland, Sweden, Norway and Hungary. More than 450 $GWh_{eq}$/a CAM could be supplied overall in 2030. CAM production could therefore cover nearly 30% of the potential cell manufacturing demand in Europe.

### 4.3.3 Anode active material

Anode active material (AAM) is currently produced in Switzerland and Poland on a pilot plant scale. These sites do not process natural graphite but use artificial graphite. Information on exact production capacities is not available. The production capacity is to be expanded in the next few years.

Additional sites to be established in Norway, Sweden, Finland, France and Germany by 2030 have been announced. Artificial or natural graphite is to be used here for AAM production. Processing natural graphite into AAM is planned in particular at sites close to graphite mining locations. The announced sites could supply AAM for more than 350 $GWh_{eq}$/a. This would cover about 20% of the potential European cell manufacturing demand.

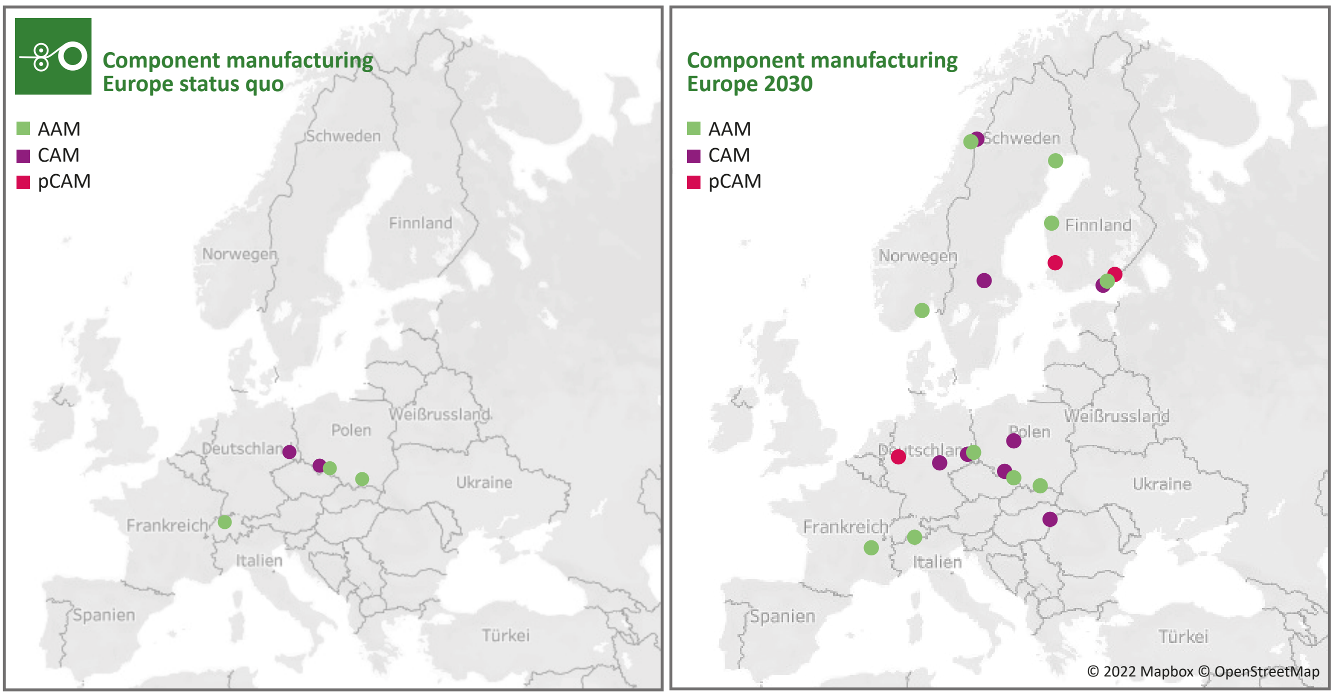



Figure 19: Component manufacturing in the region under consideration: Existing plants (left) and including plants announced until 2030 (right). In-house representation.

## 4.4 Battery cell manufacturing

Lithium-ion cells are currently being produced at several sites (Figure 20, left). Plants with large production capacities are found almost exclusively in Poland and Hungary. The operating capacity of all manufacturers in the region under consideration was around 25 GWh/a in 2021. This is expected to increase to about 80 GWh/a in 2022.

Many manufacturers have announced the construction and expansion of production facilities by 2030. The announced cell factories (Figure 20, right) have a maximum production capacity of around 1,660 GWh/a. Germany has announced the most factories and therefore also the highest production capacity. An overview of production sites in Europe is found in the market update of the Accompanying Research Team Battery Cell Production[49]. Exact locations have not yet been disclosed by the manufacturers for about 10% of the announced production capacities.

The maximum production capacity in the region under consideration could increase about twentyfold by the end of the decade. Consequently, the demand for components and materials and therefore also raw materials will increase significantly. For the examination of the supply situation, cell manufacturing capacities provided by manufacturers were rounded. A value of 80 GWh was used for 2022 and 1,600 GWh for 2030. As the Market Update Q4 2022 of the Accompanying Research Team Battery Cell Production shows, these capacities should be sufficient to fully supply European vehicle production.

## 4.5 Battery recycling

From today's perspective, the European battery recycling industry is planning sufficient capacities in the region under consideration by 2030 to process and recycle the returned traction batteries. Decentralised recycling is possible thanks to the large number of sites. There may even be capacities to recycle used traction batteries from outside the EU. Cooperation agreements for the supply of such used batteries need to be concluded in a timely manner to ensure the economic utilisation of the planned recycling facilities. A binding legal framework has to be established in the form of the European Battery Regulation, ensuring planning reliability and clearly regulating responsibilities and ownership.

Recycling sites exist in Belgium, Germany, Finland, France, Norway, Poland, Spain and Hungary among others. Thus they are represented in practically all of Europe. Various recycling steps can be carried out at the sites. For example, some sites disassemble used traction batteries, followed by pyrometallic recycling. Alternatively, disassembled batteries

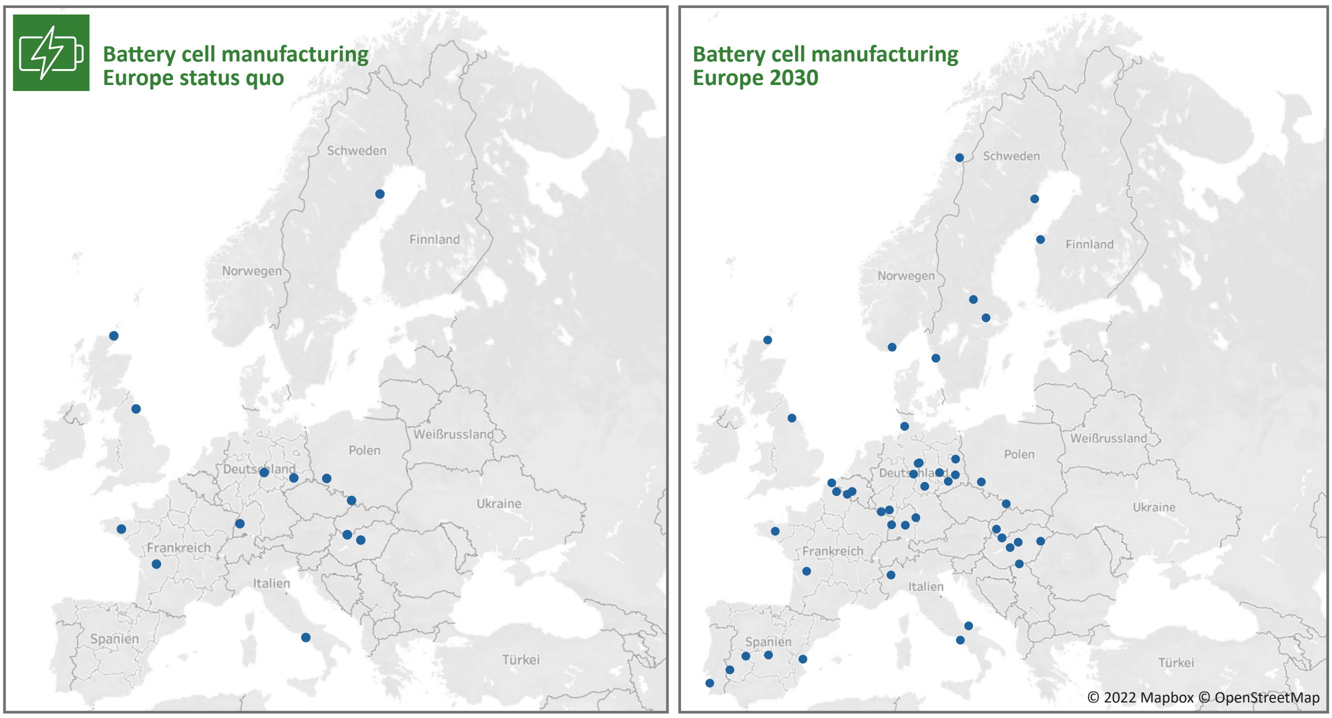



Figure 20: Battery cell manufacturing in the region under consideration; existing plants (left), and including plants announced until 2030 (right). In-house representation.

49 Market Update Q4 2022 – Accompanying Research Team Battery Cell Production (Last accessed on: 10. March 2023)

can be mechanically processed further, producing what is known as black mass. Then there are sites that process the black mass or other reclaimed recycling material using hydrometallurgical methods, making raw materials such as nickel, lithium and cobalt available to the battery industry again. The number of sites that carry out pyrometallic recycling in the first step or produce black mass is generally higher than the number of sites engaged in the further processing of the raw materials using hydrometallurgical methods. Black mass production is therefore decentralised, while reclaiming raw materials from processed black mass is centralised.

Provided the quality is adequate, the reclaimed raw material constituents can be supplied directly to the component manufacturing value-added step. If the quality is not adequate, the raw material components can be further refined in the material processing value-added step.

Recycling facilities are found in the vicinity of cell manufacturing sites, among others, e.g. in Poland and Hungary. In addition to recycling used traction batteries, these sites are specialised in particular in processing cell production waste.

A further increase in sites across Europe is observed until 2030. This growth shortens the transportation routes for defective batteries, thereby keeping logistics costs low.

Since the service life is expected to exceed ten years, the contribution of used battery recycling to the supply of raw materials is expected to be in the single-digit percentage range until 2030[50]. Circular Energy Storage, for example, expects returns of more than 300,000 tons of batteries in Europe by 2030 that have reached the end of their life cycle[51]. Assuming ideal recycling efficiency and an average specific energy of recovered batteries in the range of 100 kWh/t to 200 kWh/t, between 30 and 60 $GWh_{eq}$/a can be reclaimed. Compared to a possible production capacity of 1600 GWh/a, this corresponds to a contribution of around 2 to 4%.

The sites announced until 2030 can accept 150 $GWh_{eq}$/a of used batteries, which means they are very well equipped for the returns expected by 2030 from today's perspective. Based on the projected, pronounced increase in battery cell manufacturing capacities, it can be assumed that returns of used batteries will also increase sharply after 2030. The capacities announced to date could therefore be fully utilised quickly after 2030.

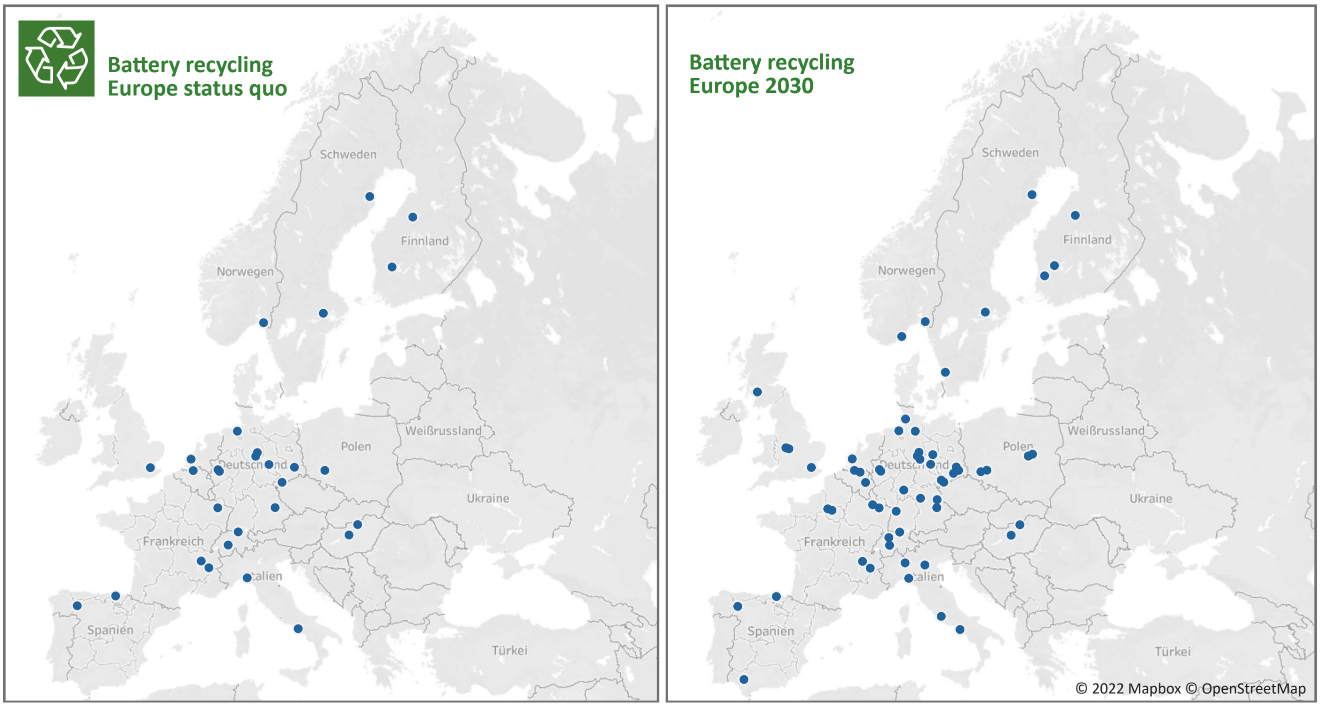



Figure 21: Battery recycling in the region under consideration; existing plants (left), and including plants announced until 2030 (right). In-house representation.

50 Metals for Clean Energy: Pathways to solving Europe's raw materials challenge (Last accessed on: 12 December 2022)

51 Circular Energy Storage – A tsunami or a drop in the ocean? (Last accessed on: 12 December 2022)

# 5 RISKS AND MEASURES

## 5.1 Self-supply potential

The supply stability of the examined battery raw materials will worsen notwithstanding all of the raw material projects announced in Europe. This is because the demand will increase even more sharply due to the considerable expansion of production capacities for battery cells. All in all, the expansion of European production and processing capacities by 2030 will contribute to higher absolute production, but this will not yet lead to a strategic autonomy.

Note that each raw material is associated with individual risks:

- **The availability of lithium is the bottleneck** for the ramp-up of battery cell manufacturing in Europe. Lithium is one of a few elements for batteries that cannot be substituted at this time. With an expected 88% market share in 2030, batteries will be the largest lithium consumer by far. If all lithium projects announced in Europe are realised, Europe could cover ~26% of its demand for lithium raw material and ~44% for refining. These projects are important since a global supply deficit

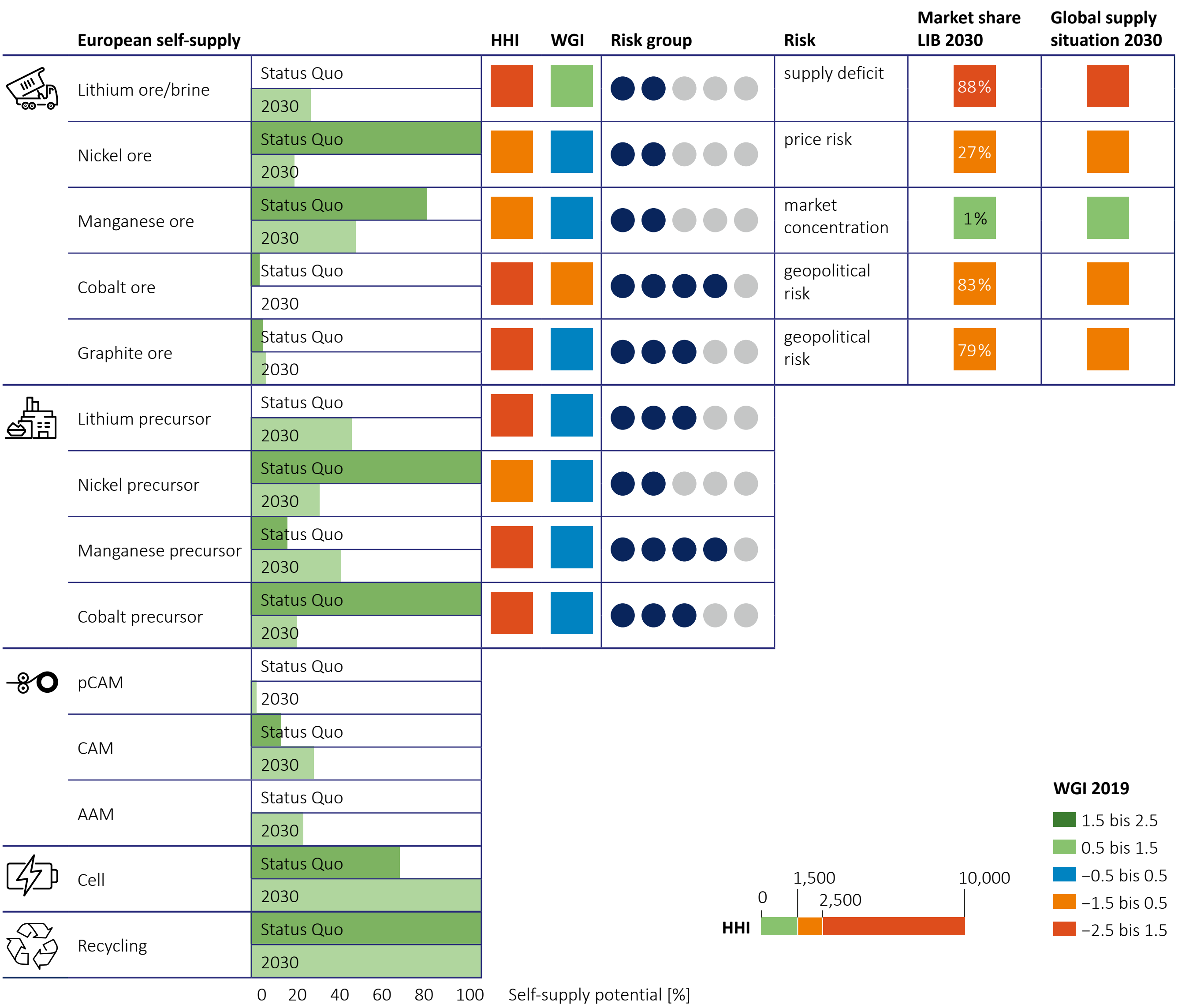



Figure 22: Overview of Europe's potential own supply in the battery value chain (left) and the global risks (right). In-house representation.

is predicted by 2030. Extremely high spot market prices indicate that a market for lithium no longer exists at this time. Anyone who has failed to conclude long-term supply contracts will not be able to get lithium now. Every lithium project in Europe will alleviate the lithium shortage and strengthen Europe's strategic sovereignty in this key market.

- **The price of nickel** is the biggest cost driver for modern high-nickel NMC battery cells. Europe has a nickel industry but it mainly supplies the stainless steel industry at this time. New nickel projects for batteries are not on the horizon. From a geopolitical point of view, Russia is not a reliable trading partner. Indonesia as the world's largest nickel producer is willing to use its market power – with export restrictions if need be – to maximise value creation in the country (e.g. pCAM, CAM and cell manufacturing). If Europe does not succeed in securing access to nickel through strategic partnerships, value-added steps in battery cell manufacturing that are important from a strategic and ESG perspective could take place outside Europe.
- **The market for manganese precursors is small and highly concentrated.** Manganese ore refining is dominated by China at more than 90%. Europe has its own access to raw materials but this is not sufficient for its own supply. With a share of less than 1%, lithium-ion batteries will only have a very small effect on the commodities market.
- **The geopolitical risk for cobalt** remains high. The Democratic Republic of the Congo remains the leading cobalt producer and China the most important country for refining. Europe only has low cobalt production. European cobalt refineries are largely supplied through imports. New projects in Europe are not foreseeable. Europe will have to depend on strategic partnerships to cover its demand. Innovations in the battery sector over the last few decades considerably reduced the cobalt content in battery cells. However, full substitution (with the exception of LFP) has not reached market readiness yet.
- **The geopolitical risk for graphite remains high.** Europe has a very small own supply. China holds a highly dominant position in the graphite market for battery anodes (close to 100%). The number of new projects currently announced for Europe is very small. Artificial graphite could eliminate this dependency and restore greater strategic sovereignty for Europe – provided site conditions are favourable.
- **No pCAM and CAM production without raw materials.** Currently no pCAM sites are known in Europe who already started producing. There were only a few announcements until 2020 which could be researched. This process step may be carried out concurrently by some CAM production sites. Assuming access to raw materials, Europe could produce 27% of its cathode materials itself by 2030.
- **Cell manufacturing and recycling assured?** All of the announced cell manufacturing and recycling projects would suffice to cover 100% of the demand for battery cells and recycling in Europe by 2030. Whether all of these projects will actually be realised under the new economic constraints remains uncertain.

## 5.2 Measures

Robust supply chains are essential to avoid endangering of the intended expansion of European battery production until 2030 and beyond. In particular, access to battery raw materials from primary and secondary sources has to be secured. Trade restrictions on raw materials of strategic importance must be given greater weight in the business risk assessment going forward.

Experiences gained from recent global supply chain disruptions, for instance due to the COVID-19 pandemic, lead to the conclusions discussed below regarding the design of stable battery raw material supply chains.

The concept of supply chain resilience is helpful for classification. It refers to the ability of a supply chain to respond to external and abrupt disruptions. This classification can be used to compare the effects of various types of disruptions (e.g. pandemic, military conflict, political crisis, blocking of a transportation route) and to draw generally applicable conclusions for the improvement of resilience. Resilience in raw material supply chains is exposed to the challenge that technological innovations can lead to an increase in demand, but that the supply in the raw material markets can be adjusted with a time lag due to the limited geological availability.[52]

The following factors typically contribute to high **supply chain resilience**:[53]

1. **Robustness:** This comprises factors that can alleviate the reduction of supply chain performance and enable

52 https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-52.pdf?__blob=publicationFile&v=6 (Last accessed on: 12 December 2022)

53 https://opus4.kobv.de/opus4-th-wildau/files/1597/Schmidt_2021_Resilienz_Corona_Pharma_Automobil.pdf (Last accessed on: 12 December 2022)

potential high performance at the end of the crisis, for example, through the standardisation of processes and redundant capacities.
2. **Agility:** Responsiveness and flexibility help with overcoming a crisis quickly. Contributing factors include transparency measures, monitoring and systematic risk management, but also decentralised production and storage sites.
3. **Indirect factors:** Resilience is improved when stakeholders are engaged in an ongoing learning process and maintain a modern company culture.

Based on a study of several industry sectors, four central spheres of activity can be derived from this. Proposed measures to improve the resilience of battery raw material supply chains can be defined for these according to the results of the above risk analysis (Figure 23):[54]

1. **Implement digitalisation and transparency:** Supply chain agility benefits from the availability of information between market participants and various value-added steps. Digitalisation offers an opportunity here, for example, through the introduction of standardised digital product passports for raw materials, intermediate products and batteries. High shared standards in IT security and information rights management contribute to mutual trust between the stakeholders. This enables monitoring and the sharing of information on supply flows in real time.
2. **Diversify supply chains, improve recycling:** Activities to develop new production sites (multi-sourcing) or additional suppliers and storage sites, but also measures to make production methods more flexible in order to reduce dependencies on special intermediate products, improve the agility and the robustness of supply chains. A greater product variety, especially for cell chemicals, natural versus artificial graphite and NCM versus LFP, can also reduce the risk of supply failures. Recycling is increasingly contributing to relieve the supply situation at this stage[55] and can alleviate the future increase in the demand for raw materials in terms of a full recycling economy. Increasing returns of used traction batteries can be expected after 2030, so that the prerequisites for efficient recycling processes (e.g. recycling-friendly cell design, processing capacities) should already be established today.
3. **Balance security of supply and storage costs:** The suggestion to maintain buffer capacities for important precursors in supply chains is often countered with the argument of high costs or "dead capital" due to the

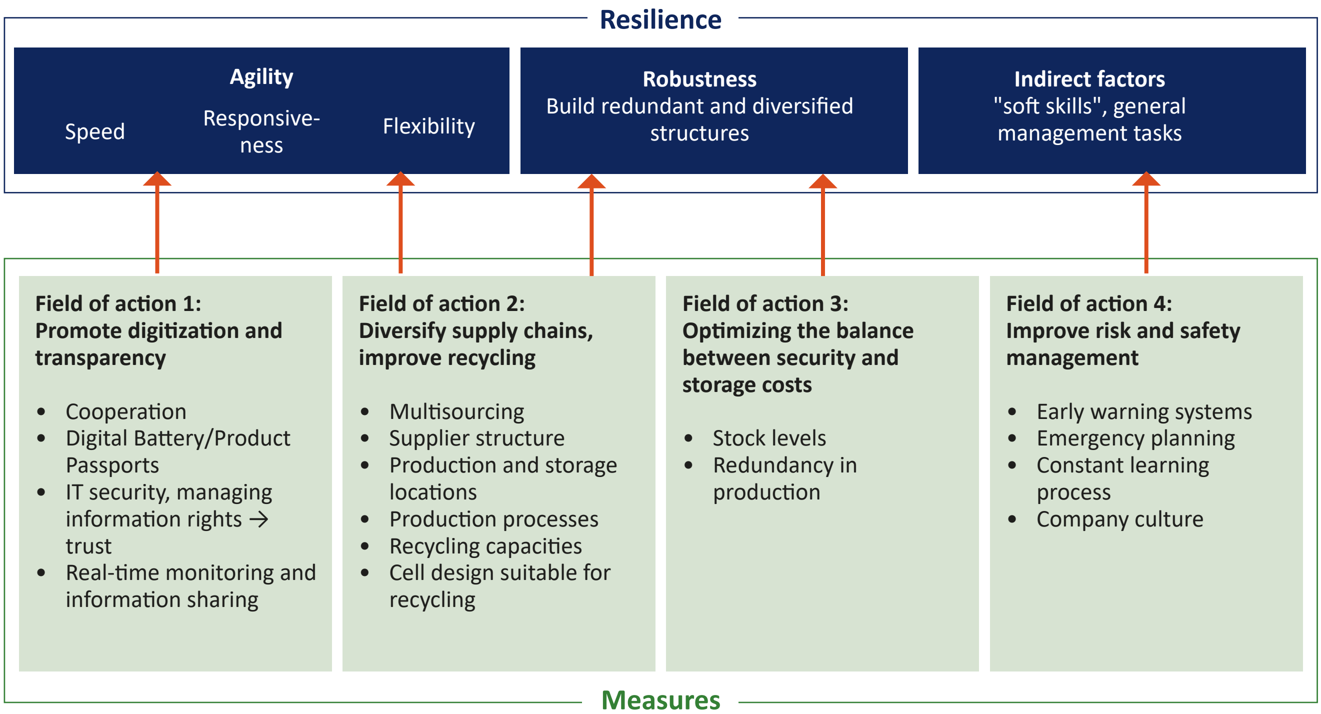



Figure 23: Success factors for supply chain resilience and derived proposed measures. Arrows indicate the effect of measures on the various dimensions of resilience. In-house representation based on Schmidt (2021), https://opus4.kobv.de/opu

54 https://link.springer.com/content/pdf/10.1007/978-3-662-66057-7_8.pdf?pdf=inline%20link (Last accessed on: 12 December 2022)

55 https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-52.pdf?__blob=publicationFile&v=6 (Last accessed on: 12 December 2022)

storage of expensive substances. An entrepreneurial balance between storage costs and estimated costs due to the effects of a supply chain disruption therefore has to be established.

4. **Implement consistent risk and security management:** Implementing early warning systems and emergency plans to respond to acute disruptions, but also an ongoing learning process and an open, diverse company culture can indirectly strengthen resilience. Progress has already been made here in the last few years (in part due to recent global crisis situations such as the COVID-19 pandemic). Examples include digital meetings and location flexibility in the working world, even after the end of lockdowns caused by the pandemic. The potential of these measures has not been exhausted yet.

### Manufacturers are taking steps to secure raw materials

Manufacturers of battery cells and components are already taking steps to secure raw materials: According to a study[56] by PwC on behalf of DERA, the most common measures currently are

- the diversification of suppliers,
- increased efforts to conclude long-term delivery contracts and
- improving business tools in procurement planning.

The goal of the **diversification of suppliers** is for businesses to weigh comparatively low-risk but therefore generally more expensive procurement options (e.g. newly established European sites) against lower-cost but more risky sources on the other hand. A mix of both strategies is recommended, for example, by covering the regular production throughput by procuring raw materials at favourable costs from a country with a high WGI, but having another procurement option available to maintain a minimum production volume. Such a combination can be assigned to the current trend towards "glocalisation" of the industry.

The potential for **recycling** and further improving the material efficiency is not as extensively realised to date. Reasons for this include:

- Returns of used traction batteries are only expected to increase significantly after 2030 according to current projections. Recycling cannot make a major contribution to lowering the demand for raw materials until then. (There is no question that recycling in terms of a full recycling economy is nevertheless sensible even today.)
- Return rates below 100% for used traction batteries and a cell design that does not take subsequent recycling into account impose additional limits on the contribution of recycling. Implementing recycling readiness in the cell design and consistently enforcing the EU recycling target quotas therefore suggest themselves as supplementary measures.

The effects of the **trend in favour of long-term supply contracts** (and the extent to which the demand for certain raw materials is already covered by contracts with a specified term) cannot be reliably assessed at this time. Isolated reports from companies regarding the conclusion of an especially comprehensive, long-term supply contract indicate that companies have become more aware of the problem but do not provide a comprehensive picture.

Additional proposed measures use **raw material prices** as the starting point: A possible response to the shortage of a raw material is to **pass rising prices along the supply chain** to the end customer. Price signals have a control effect in the market economy. Even when a supply shortage occurs suddenly within a short time, for instance due to a political crisis or a military conflict, companies can pass the short-term price increase on to customers in whole or in part. However, this hardly reduces risks for the supply chain as a whole since buyers are generally not able to realise an efficient response to the price increase in the short term, e.g. through substitution of the product. A sudden price increase can therefore have a disruptive effect on the entire downstream supply chain. (The natural gas price increase in the course of 2022 is an example: End customers can reduce their consumption to a minor extent, but not switch to a different heat source in the short term. Thus, the sudden shortage only has a very limited control effect for substitution of the energy source in the short term.)

Stabilising the entire supply chain in case of short-term shocks is more readily achieved by cushioning or a delay in passing on the price signals. Financial market instruments to protect against price change risks are appropriate here (commodity price hedging). From the perspective of the overall chain, they work as insurance against sudden shortages and associated price fluctuations.

A number of **government tools** are available at the national level to reduce supply chain risks in the battery value chain.

56 https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-52.pdf?__blob=publicationFile&v=6 (Last accessed on: 12 December 2022)

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| BMWK | Federal Ministry for Economic Affairs and Climate Action of the Federal Republic of Germany |
| BEV | Battery electric vehicle |
| EMM | Electrolytic manganese metal |
| MSM | Manganese sulphate monohydrate |
| CAM | Cathode active material |
| AAM | Anode active material |
| pCAM | Precursor for cathode active material |
| LCE | Lithium carbonate equivalent |
| LIB | Lithium-ion battery |
| NEV | New electric vehicle |
| PHEV | Plug-in hybrid electric vehicle |
| FCEV | Fuel-cell electric vehicle |
| EU COM | European Commission |
| EV | Electric vehicle |
| OEM | Original equipment manufacturer |
| NMC | Lithium nickel manganese cobalt oxide |
| NCA | Lithium nickel cobalt aluminium oxide |
| LMO | Lithium manganese oxide |
| MSP | Mixed sulphide precipitate |
| MHP | Mixed hydroxide precipitate |
| $GWh_{eq}/a$ | Gigawatt hour equivalent per year |
| HHI | Herfindahl-Hirschman index |
| WWGI | Weighted WGI |
| AAM | Anode active material |
| EMM | Electrolytic manganese metal |
| MSM | Manganese sulphate monohydrate |
| LF(M)P | Lithium iron (manganese) phosphate |
| DERA | Deutsche Rohstoff Agentur (German Raw Materials Agency) |

# GLOSSARY

Gigafactories
Name for production facilities that produce battery cells annually on a gigawatt hour scale

Reserves
The quantity of a raw material that can be developed and extracted using state-of-the-art technology. The technical and economic feasibility of extraction have been proven.

Resources
The amounts of a raw material that are given or proven in principle but have not been developed yet. The technical and economic feasibility of extraction have not been proven yet.

Raw materials
Extracted/mined reserves (not processed) that are required for a production process.

Refined material production
A technical process in which a raw material is purified, refined or processed further.

pCAM
Precursor for cathode active material, an input material for the production of cathode active material (CAM). pCAM contains nickel, cobalt and manganese in the desired stoichiometric proportions for CAM production.

Black mass
Produced during the recycling of LIBs. It mainly consists of the CAM and AAM as well as other components added to the active material during the coating process.

Commodity price hedging
Using financial products to counteract financial risks such as rising commodity prices.

Hard rock
Hard stone, used in the context of lithium as an umbrella term for ores containing lithium.

NMC 622 cells
A lithium-ion battery using NMC with a nickel-manganese-cobalt ratio of 60:20:20 as the cathode material.

NMC-811 cathodes
A lithium-ion battery using NMC with a nickel-manganese-cobalt ratio of 80:10:10 as the cathode material.

Glocalisation
A word coined from the terms globalisation and localisation.

EFTA
European Free Trade Association

# APPENDIX

**Weighted WGI:**
The Worldwide Governance Indicators consist of six dimensions comprising 30 individual indicators. They indicate the perception of the quality of governance based on a large number of survey results.[57] The data have been collected since 1996 and are provided by the World Bank.[58] The WGI for a country is the average of the six dimensions. A weighted WGI (e.g. for a group of goods) is the average of the product of the WGI and the country's share in the trade. Weighted or not, WGI values lie in the range of -2.5 to +2.5 and are assigned to five evaluation categories (-2.5 to -1.5 *very high*, >-1.5 to -0.5 *high*, >-0.5 to +0.5 *moderate*, > +0.5 to +1.5 *low*, > +1.5 to +2.5 *very low*).

**Herfindahl-Hirschman index (HHI):**
This indicator describes the country concentration. The sum of squares is calculated for all involved shares (in per cent). Thus the Herfindahl-Hirschman index can have values from 0 to 10,000. There are three categories for evaluation: 0 to < 1,500 *low*, 1,500 to < 2,500 *moderate* and over 2,500 *high*. This country concentration indicator goes back to Albert O. Hirschman (1945) and Orrin Herfindahl (1950).

**Evaluation of risk groups**
Categorisation in five risk groups can be performed through the joint application of the country concentration (HHI) and World Governance Indicators (WGI). The figure below shows the risk portfolio prepared for this purpose, respectively with three ranges for the HHI and WGI. For the HHI, the low and moderate country concentration were combined and a reference line was drawn to divide the high country concentration at HHI = 6,500 (corresponds to > 80% country concentration of a party).

**Trade data**
All trade data were researched in the Trade Map[59] database. For the elements lithium, nickel, manganese, cobalt and graphite examined in this study, trade volumes were retraced starting from the countries where they are mined (see Section 3), beginning with the raw material (ores) and ending with raffinates. For example, county A mines substance X and exports it as ore to countries B and C. Trade volumes from countries A, B and C were then researched for the raffinates. When the raffinates served as potential intermediate products for further processing, the same approach was used in researching the trade data.

All researched trade data are what is known as "mirror data". This allows what are called "trade data effects" through larger seaports (e.g. Rotterdam in Europe) to be avoided, since the goods are often transported further. For example, Brazil reports the export of product XY to the Netherlands (by ship to Rotterdam). The Netherlands are therefore listed as a disproportionately large importer in global trade. However, the goods are transported further to their destination in Germany. These trade data are not always accessible/reported due to the tariff union. In terms of the "mirror data", the importer in Germany would however report the receipt of product XY from Brazil to the applicable authorities.

In the course of data research in the Trade Map database, data were therefore identified with the question: "What country imported substance X from country A?". The same dataset can therefore be used to determine who imported substance X and who exported substance X. Import and export quantities were then correspondingly added together for each country involved. Only the quantities for countries in the region under consideration were added together for imports into the region under consideration.

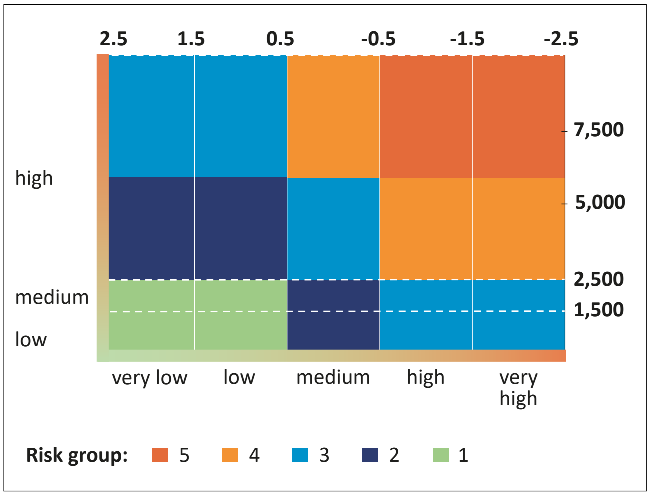


Figure 24: Visualisation for the evaluation of risk groups

57 The Worldwide Governance Indicators: Methodology and Analytical Issues by Daniel Kaufmann, Aart Kraay, Massimo Mastruzzi: SSRN [https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1682130] (Last accessed on: 12 December 2022)

58 http://info.worldbank.org/governance/wgi/ (Last accessed on: 12 December 2022)

59 www.trademap.org (Last accessed on: 12 December 2022)

Please note that uncertainties remain for trade data in general, notwithstanding all diligence in research. The data in the Trade Map database are based on the international trade database Comtrade[60] and Trade Map's own research in national customs databases. It is nevertheless possible that trade data are not recorded. This can happen for trade between countries in tariff or trade unions, for example, and also when trade with certain product groups is not disclosed for national reasons.

### Calculation of $GWh_{eq}$

The following table shows how many kilograms of lithium, nickel, manganese and cobalt are needed to produce 1 kWheq NMC-622 and 1 $kWh_{eq}$ NMC-811. Multiplication by the factor $10^6$ converts kWheq to $GWh_{eq}$.

The following assumptions were made for the input material:

1 kg $Li_2CO_3$ contains 0.19 kg Li
1 kg $LiHO*H_2O$ contains 0.17 kg Li
1 kg $NiSO_4*6H_2O$ contains 0.22 kg Ni
1 kg $MnSO_4*H_2O$ contains 0.33 kg Mn
1 kg $CoSO_4*7H_2O$ contains 0.21 kg Co

Table 2: Raw material content per kilowatt hour for three different material classes

| Material | Li content [kg/kWh] | Ni content [kg/kWh] | Mn content [kg/kWh] | Co content [kg/kWh] | C content [kg/kWh] |
|---|---|---|---|---|---|
| **NMC-622** | 0.11 | 0.55 | 0.17 | 0.18 | - |
| **NMC-811** | 0.10 | 0.66 | 0.08 | 0.08 | - |
| **AAM (graphite)** | | | | | 0.88 |

60 https://comtrade.un.org/data (Last accessed on: 12 December 2022)