re-sourcing

State of Play and Roadmap Concept: Mobility Sector

RE-SOURCING Deliverable 4.2

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List of Abbreviations

2DS	two-degree climate scenario
3R	reduce, reuse, recycle
3TG	tin, tungsten, tantalum, and gold
ACEA	European Automobile Manufacturers' Association
Al	aluminium
AMD	acid mine drainage
ARM	Alliance for Responsible Mining
ASM	artisanal and small-scale mining
BEV	battery electric vehicle
BGR	German Federal Institute for Geosciences and Natural Resources
C	carbon
CCCMC	China Chamber of Commerce of Metals, Minerals & Chemicals Importers and Exporters
CI	Cobalt Institute
CIRAF	Cobalt Industry Responsible Assessment Framework
CMRT	Conflict Minerals Reporting Template
Co	cobalt
Cr	chromium
CRAFT	Code of Risk mitigation for ASM engaging in Formal Trade
CRT	Cobalt Reporting Template
CSR	corporate social responsibility
CSR Europe	European Business Network for Corporate Sustainability and Responsibility
CTC	certified trading chains
Cu	copper
E-	electric
EBA	European Battery Alliance
EBRD	European Bank for Reconstruction and Development
EHS	environmental health and safety

EITI	Extractive Industries Transparency Initiative
eLI	European Lithium Institute
ELV	end-of-life vehicles
EoL	end-of-life
ESG	environmental, social, governance
EU	European Union
EU27	27 Member States of the European Union
EU-OSHA	European Union Information Agency for Occupational Safety and Health
EV	electric vehicle
FCA	Fair Cobalt Alliance
Fe	iron
GBA	Global Battery Alliance
GHG	greenhouse gas
GIZ	German Corporation for International Cooperation GmbH
GRI	Global Reporting Initiative
H	hydrogen
HEV	hybrid electric vehicles
HF	hydrofluoric acid
ICE	internal combustion engine
ICMM	International Council on Mining & Metals
IFC	International Finance Corporation
ILO	International Labour Organisation
IRMA	Initiative for Responsible Mining Assurance
ISO	International Standards Organisation
ITSCI	International Tin Supply Chain Initiative
LFP	lithium iron phosphate
Li	lithium
LIB	lithium-ion batteries
LME	London Metal Exchange
LMO	lithium ion manganese oxide
LSM	large-scale mining

LTO	lithium titanium oxide
Mn	manganese
N	nitrogen
NABU	Nature and Biodiversity Conservation Union
NCA	lithium nickel cobalt aluminium oxide
NG	natural graphite
NGO	non-governmental organisation
Ni	nickel
NMC	lithium nickel manganese cobalt oxide
NMP	N-methyl-2-pyrrolidone
O	oxygen
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
P	phosphorus
PCB	printed circuit board
PGM	platinum group metals
PHEV	plugin-hybrid electric vehicles
PVDF	polyvinylidene difluoride
R&D	research & development
RCI	Responsible Cobalt Initiative
RJC	Responsible Jewellery Council
RMAP	Responsible Minerals Assurance Process
RS	responsible sourcing
RSBN	Responsible Sourcing Blockchain Network
SDG	Sustainable Development Goals
SEI	solid-electrolyte interphase
SG	synthetic graphite
SoH	State of Health
SoP	state of play
Ti	titanium
TSM	Towards Sustainable Mining

TR	thermal runaway
VDA	German Association of the Automotive Industry
WBCSD	World Business Council for Sustainable Development
WEEE	Waste Electrical and Electronic Equipment
WWF	World Wide Fund For Nature, or World Wildlife Fund
xEV	all types of electric vehicles

Country codes

BE	Belgium
CN	China
CA	Canada
CH	Switzerland
D	Germany
DRC	Democratic Republic of the Congo
HK	Hongkong
JP	Japan
KOR	South Korea
NOR	Norway
USA	United States of America

Executive Summary

Meeting the Paris Agreement's goals requires transformation in the mobility sector. Battery electric vehicle technology today offers a promising technology to achieve the necessary changes and transform the sector. Yet this transformation goes hand in hand with a significant increase in the raw material demand for lithium-ion batteries.

This document provides an overview on the current status of the mobility sector, focusing on three selected value-chain steps for lithium-ion batteries – raw material mining, battery cell production and battery recycling – and four relevant materials: lithium, cobalt, nickel and graphite.

Key players and sustainability challenges along the supply chain steps were identified for this analysis. Mining faces a wide range of challenges, which are raw-material and site-specific. Overarching challenges in hard rock or ore mining (for the selected materials lithium, cobalt, nickel and graphite) include heavy metal pollution, acid mine drainage, energy intensive processing, habitat fragmentation, disturbance of land areas and dust pollution. For lithium from brines, water scarcity and connected social tensions as well as dust emissions are major challenges. Social dimensions related to cobalt mining are an additional issue already in public discourse; the main cobalt-producing country, the Democratic Republic Congo (DRC), has a relatively high share (10-20% of production from DRC) of artisanal and small-scale mining (ASM). ASM is the income basis of thousands of families in the DRC. But the often informal ASM sector is connected to child labour, forced labour, inadequate health and safety conditions, and funding of armed conflicts.

Battery cell manufacturing also faces challenges. It is a very energy-intensive process and therefore associated with high greenhouse gas emissions. Furthermore, the toxic substances in the battery cell require proper handling. As well, high susceptibility to production errors for battery cells lead to high scrap rates in production.

Recycling of end-of-life Li-ion batteries is indispensable because of the high risk of "thermal runaway" related to overheating batteries leading to fires. Therefore, adequate collection, storage, transport and treatment of used Li-ion batteries are essential.

This report also examines existing standards and initiatives addressing these challenges. Various regulations, standards, initiatives as well as guidelines promoting sustainable practices for the mining sector were analysed. It was noted that the availability of standards and frameworks for the battery cell manufacturing and recycling steps are rather limited while other value chain steps are covered in numerous initiatives.

A gap analysis was conducted to assess whether the standards and initiatives cover the challenges that exist in the supply chains. In the mining sector, one identified gap is the very large and confusing number of guidelines. There is no international framework that also provides mutual recognition of standards. Such a framework would define terms and provide guidance for companies on which standards to apply. For customers, too, knowing which standards and corporate qualities are relevant is challenging.

These difficulties in knowing what standards are best also apply to battery cell manufacturing and the collection and recycling of end-of-life Li-ion batteries. There are no international guidelines addressing the whole supply chain. The proposal for an EU Regulation on (waste) batteries could offer an important step to integrate crucial elements of the supply chain in a regulation (supply chain due diligence, product carbon footprint, material specific recycling targets, recycled content etc.).

Resource efficiency is a relevant lever to reduce the negative impacts in primary extraction. Especially when considering the rapidly increasing demand for raw materials in the growing market of electric vehicles, a decoupling of economic growth from resource consumption is necessary.

As a first step in the Roadmap process, an overarching vision was developed with various goals that need to be achieved by 2050 to ensure a sustainable and responsible value chain in the mobility sector. The basis of this vision is built on the concepts of planetary boundaries and strong sustainability.

1 Introduction and Focus

This report is the first publication of the in-depth work in the mobility sector. It provides an overview of the current status of this sector, with a focus on Li-ion batteries, the key players, challenges and selected standards and initiatives. In the coming months, the mobility Roadmap will be developed with different stakeholders. In parallel, good practice examples of approaches for responsible sourcing will be researched. Selected good practice examples – 'Flagship' Cases – will be included in the Flagship Labs at the end of 2021 into early 2022. In these Labs, Flagship Cases will be promoted to other actors in the value chain for implementation in other companies or institutions. A good-practice guidance document will summarise these approaches and will be included in the final Roadmap, which will be published in summer 2022.

1.1 The RE-SOURCING Project

Responsible Sourcing (RS) is becoming a reality for more and more businesses and policymakers, and it is increasingly demanded by both NGOs and civil society. Everyone is striving to keep ahead of rapidly evolving ecological and social needs, company practices, business models, government regulations, and initiatives spearheaded by civil society, etc.

In response to the growing challenge of responsible sourcing, **the RE-SOURCING Global Stakeholder Platform has been started in 2020**.

RE-SOURCING, funded under the European Union's (EU) Horizon 2020 programme, is a four-year project (November 2019 to October 2023) coordinated by the Institute for Managing Sustainability at the Vienna University of Economics and Business. The project's consortium consists of 12 international partners in- and outside the EU, working together to create the RE-SOURCING Platform. The project's vision is to **advance and establish Responsible Sourcing as a minimum requirement among EU and international stakeholders**. The project fosters the development of a globally accepted definition of Responsible Sourcing, facilitate the implementation of RS practices through direct knowledge exchange within its network and beyond, and advocate for Responsible Sourcing in international political forums.

To guarantee a thorough and comprehensive Responsible Sourcing framework, RE-SOURCING takes a holistic approach by integrating firms and industries (up- and downstream) **across the mineral value chains of three sectors**: Renewable Energy, Mobility and Electronics – all of which play a decisive role in the EU Green Deal and the clean energy transition. As such, RE-SOURCING equally takes into account traditional minerals, conflict minerals and green tech minerals in its approach. The main target groups of the project are the EU and international industry stakeholders, EU policymakers and civil society.

The RE-SOURCING project's actions seek to:

- facilitate the development of a globally accepted definition of RS;
- develop ideas for incentives facilitating responsible business conduct in the EU, supporting RS initiatives;
- enable the exchange of stakeholders for information and promotion of RS;
- foster the emergence of RS in international political fora; and
- support the European Innovation Partnership on Raw Materials.

RE-SOURCING will deliver:

- *For EU and international business stakeholders:*
  - *increased capacity of decisionmakers for implementing responsible business conduct;*
  - *better understanding and awareness of RS in three sectors: renewable energy, mobility and electric and electronic equipment; and*
  - *facilitated implementation of lasting and stable sectoral framework conditions for RS.*
- *For EU policymakers:*
  - *increased capacity for RS policy design and implementation;*
  - *innovative ideas on policy recommendations for stimulating RS in the private sector; and*
  - *better understanding and awareness on RS in three sectors: renewable energy, mobility and electric and electronic equipment.*
- *For civil society:*
  - *integration of sustainable development and environmental agendas into the RS discourse;*
  - *an established, global level playing field of RS in international political fora and business agendas; and*
  - *better understanding and awareness on RS in three sectors: renewable energy, mobility and electric and electronic equipment.*

1.2 The Mobility Sector

The mobility sector plays an important role in worldwide efforts to achieve the goals of the Paris Climate Agreement. As well, the European Green Deal requires a 90 % reduction of emissions from transport by 2050 to achieve climate neutrality. In 2018, the mobility sector accounted for 30 % of total EU greenhouse gas (GHG) emissions, as can be seen in Figure 1 below. Road transportation is of highest relevance, with more than 70 % of the GHG emissions from the transportation sector (aviation, navigation and railways play a minor role).

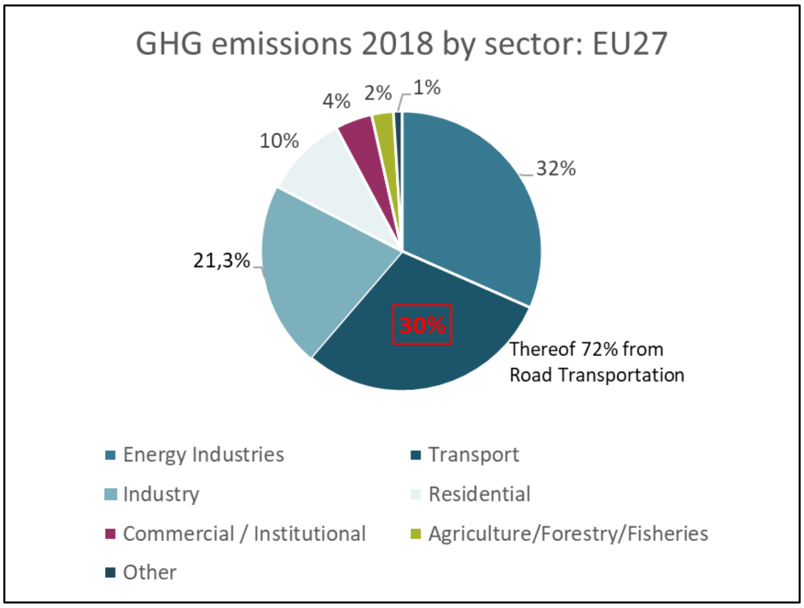


Figure 1: Greenhouse gas emissions 2018 by sector in the European Union (EU27) (Source: European Commission 2020a)

This project focuses on road transportation due to the significant contribution to overall GHG emissions. One of the RE-SOURCING project goals is to develop a Roadmap for responsible sourcing in the mobility sector by 2050. The project's focus on the mobility sector value chain hence concentrates on future technology in road transportation – electric vehicles – as it is seen as key for a transition to transportation with lower GHG emissions. Indeed in 2050, it is predicted that 80 % of all newly registered passenger vehicles worldwide could be equipped with alternative drive systems (Oeko-Institut 2019).

Many automobile manufacturers and automotive supply companies have already shifted their business plans towards electric vehicles and their components. For example, VW recently announced its wish to increase the share of BEV sales in Europe from the initially planned 35 % to 70 % by 2030 (Electrive.net 2021). BMW plans to sell 7 million electric vehicles (two-thirds BEVs) by 2030 (Ecomento 2020). Similar announcements are true for many other companies from the EU automotive industry. At the same time, the automotive industry's general standard of due diligence in the chain of custody, i.e. in the record of ownership or usage, is very low (WBA 2020). Some original equipment manufacturers (OEMs) are not only involved in the production and recycling of battery cells but go further up the value chain and invest in resource production itself, mostly to secure their share of certain resources (BMI 2020c). However, this also creates even more opportunities to hold them accountable for ESG (environmental, social, governance) performance.

In Table 1, there is a list of selected key players (Europe / global) in the automotive supply chain that focus on electric vehicles.

Table 1: Overview of some key players in the automotive supply chain, omitting sourcing and smelting

Level	Europe-based companies	Companies mainly based outside Europe	Product
1st tier	Volkswagen AG (D), Renault-Nissan-Mitsubishi (NL), Stellantis N. V. (NL) BMW (D), PSA (F), Daimler (D)	Toyota (JP), Hyundai Motor Group (KOR), GM (USA), BYD (CN), Suzuki (JP), BAIC Group (CN), SAIC (CN), Geely (CN), Tesla (USA)	Original equipment manufacturer (OEM)
2nd tier	BASF (D), Umicore (BE)	Johnson Matthey (UK)	Catalyst manufacturer
2nd tier	ZF (D), Continental (D), Bosch (D), Magneti Marelli (I), Valeo (F), Michelin (F), Mahle (D), Faurecia (F)	Denso (JP), Magna (CA), Hyundai Mobis (KOR), Aisin (JP), Bridgestone-Firestone (JP), Lear (USA), Delphi (USA)	Automotive parts (motors and others)
2nd tier	Siemens (D), VW (D), Bosch (D), SEW Eurodrive (D), ZF (D), Schaeffler (D), Brose (D), ABB (CH)	Toshiba (USA), Nidec (JP), Rockwell Automation (USA), AMETEK (USA), Regal Beloit (USA), Johnson Electric (HK)	E-Motor
2nd tier	BMZ (D), Bosch (D), Akasol (D), Deutsche Accumotive GmbH (D, Daimler)	LG Chem (KOR), Panasonic (JP), Tesla (USA), Samsung SDI (KOR), CATL (CN), BYD (CN), Clarios (USA, PB Battery)	Battery manufacturer
	PSA (F), VW (D), Northvolt (SWE), Freyr (NOR), Leclanché (D)	LG Chem (KOR), CATL (CN), Panasonic (KOR), Tesla (USA), BYD (CN), Svolt (CN), Farasis (USA/CN), Microvast (CN), SK Innovation (KOR), Samsung SDI (KOR)	Cell manufacturer
3rd tier	Umicore (BE), BASF (D)	Shanshantech (CN), NEI (USA), Nichia (JP), Easpring (CN), L&F (KOR)	Cathode material producer

3rd tier	SGL Carbon (D)	Shenzhen BTR (CN), Hitachi (JP), Mitsubishi (JP), Shinzoom (CN), ShanShan (CN), Sinuo (CN), Zichen (CN)	Anode material producer (natural and synthetic graphite)

Today, the most promising technology for the future of alternative drive systems is the battery electric vehicle (BEV). In this context, the production of strong, efficient and affordable batteries is essential. As the traction battery is the most valuable part of an electric car, with 40 % of the value chain (BMWI 2021), the RE-SOURCING project focuses on traction batteries for electric passenger cars. The immense impact of the electric-vehicle market on the production of lithium-ion batteries (LIBs) is described in chapter 2. It is not yet clear if other technologies, like hydrogen fuel cell technology, will gain a higher market share for vehicles in the future or remain a niche product (Hebling et al. 2019).

For vehicle batteries, the research here focused on current lithium-ion technology and manufacturing processes. This includes graphite anodes and lithium nickel cobalt manganese oxide ($LiNi_xMn_yCo_zO_2$, NMC) cathodes. Recent automotive trends use LIBs with a lithium iron phosphate ($LiFePO_4$, LFP) cathode for small cars, as the battery cells are currently cheaper; LFP batteries are already very common in China. Whether this trend will continue in Europe or move back towards NMC cathodes is difficult to project. Future technologies, such as solid-state batteries or non-lithium battery chemistries, are not part of this document as they do not yet play a role in the battery cell market and it is difficult to predict whether and to what extent their major technological challenges will be overcome to allow future use.

The mobility sector as a whole requires a wide range of raw materials. These materials differ according to application, such as body frame, wheels, cables, motors or batteries. Apart from other materials like plastics, including rubber for tires, the major metals used in the mobility sector are:

- “Traditional” metals, like steel (e.g. for body frame, engine, transmission and wheels), copper (e.g. for cables, LIBs, electric engine, electronics) and aluminium (e.g. for light weight construction);
- Conflict minerals: 3TGs (tin, tungsten, tantalum, and gold; for e.g. electronics like the battery management system); and
- Green technology materials, like rare earth elements (e.g. for permanent magnets in electric motors), platinum group metals (e.g. for catalytic converter of fuel cells), cobalt, lithium, nickel, natural graphite (e.g. for LIBs).

As this project focuses on the traction battery for electric vehicles, the State of Play and Roadmap will likewise focus on the LIB materials lithium, cobalt, nickel and graphite. Focus on these four materials results from the fact that the development of the LIB market has a large impact on the sourcing of these materials, as they are all crucial for the future of LIB. Furthermore, copper is excluded here since it is part of the renewable energy sector of this project (Kügerl 2021). The value chain of a LIB is very diverse. As shown in Figure 2, it can be divided into seven simplified steps: mining, precursor production, electrode material production, cell production, module and pack production, use phase and finally battery recycling. This State of Play document will focus on three of these steps: **mining, cell production and recycling** for traction batteries and the selected LIB materials, as further illustrated in chapter 2.

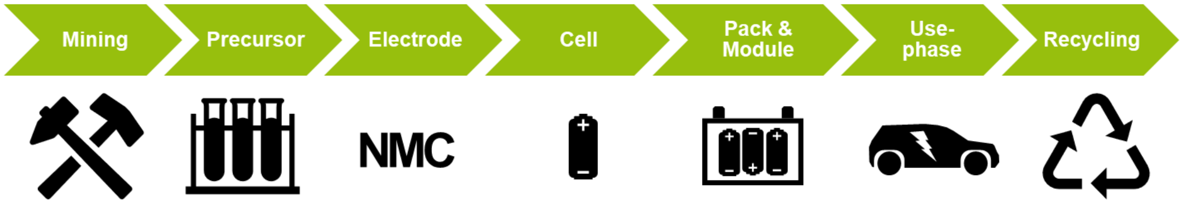
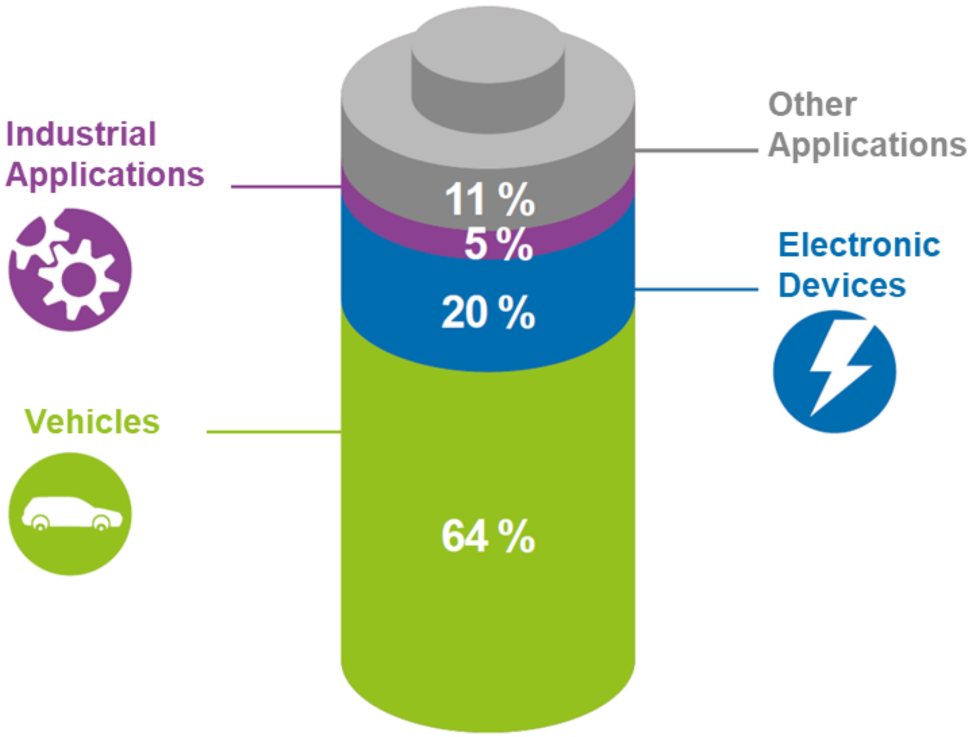


Figure 2: Value chain of a Li-ion battery (Source: Oeko-Institut)

2 Key Players in the Selected Global Battery Value Chain Steps

The mobility sector is critical for the battery market. Demand for lithium-ion batteries (LIBs) is strongly driven by the increasing demand for electric vehicles of all types, which is in turn promoted as a mitigation strategy to reduce contributions to climate change. High-performance LIBs (partially) power all types of electric vehicles, including e-bikes, hybrid electric vehicles (HEV), plugin-hybrid electric vehicles (PHEV), battery electric vehicles (BEV), electric buses and hybrid or fully electric lorries.

As depicted in Figure 3, vehicles in general used nearly two thirds of the produced LIBs in 2018, since a large number of LIBs are needed to move a vehicle compared to powering small devices. As the battery electric vehicle (BEV) market is expected to grow dramatically, the ratio of LIBs for the mobility sector is foreseen to significantly increase over the next years.



The data refers to the year 2018. Source: Pillot, Christophe (2019): Impact of the xEV Market growth on Lithium-Ion Batteries and Raw Materials Supply 2018-2030 AABC: advanced automotive battery conference. 30 Januar 2019, Strasbourg, Frankreich https://bit.ly/3mq2oPV accessed on 5.6.2020

Figure 3: Global battery market in 2018 (Source: Oeko-Institut 2020)

This strong growth is also visible in Figure 4, where global demand in batteries for electric mobility in 2016, 2030 and 2050 in a two-degree climate scenario (2DS) is depicted. Starting with ≈85 GWh in 2016, the demand rises to over 1000 GWh in this scenario by 2030 and again more than triples (6600 GWh) by 2050. This massive demand corresponds with a huge demand for more resources.

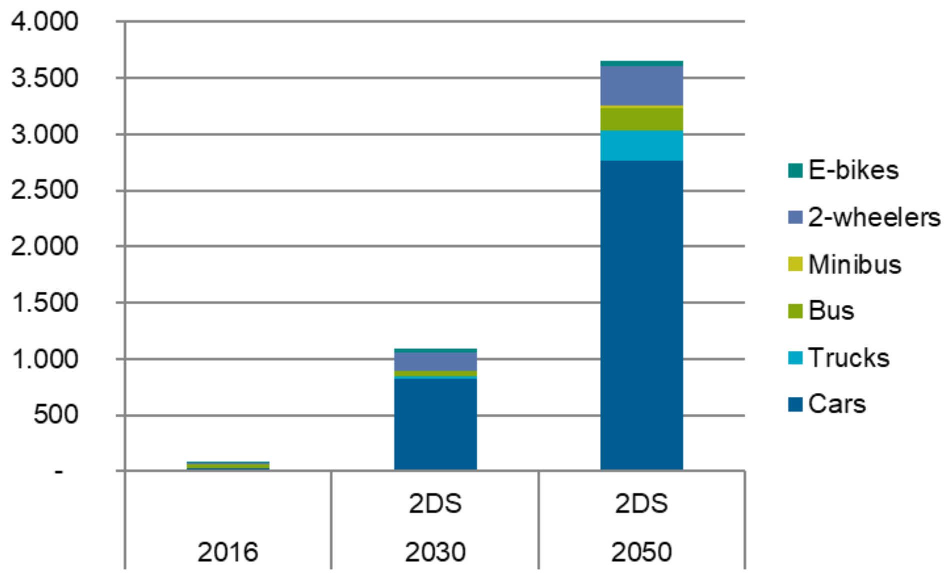


Figure 4: Global demand in batteries for electric mobility in 2016, 2030 and 2050 in a two-degree climate scenario (2DS) (Source: Oeko-Institut 2019)

To more deeply investigate the challenges of the battery value chain, we have divided it into seven steps. We focused on three of these steps, here marked in bold:

1) ***Mining***: *Mining of different materials takes place around the globe; includes the mining and refining of the key elements for LIBs (e.g. Li, Co, Ni, Cu and graphite). Many socio-economic and environmental challenges occur during the mining process (see chapter 3.1).*

2) *Precursor production: Includes e.g. the production of the cathode precursor by co-precipitation of the transition metals Ni and Co.*

3) *Electrode material production: Includes the manufacturing of active materials for the anode and cathode, binders, current collectors, separators and electrolyte including additives.*

4) ***Cell production***: *Addresses electrode manufacturing and the production and assembly of single battery cells.*

5) *Pack & module production: Usually takes place at the automobile manufacturing stage to ensure that specifications for vehicles are met; includes:*

Module production (configuration of cells into larger modules that include some electronic management);

pack assembly (Installation of modules together with systems that manage power, charging and temperature); and

vehicle integration (integration of the battery pack into the vehicle structure, including the battery-car interface).

6) *Use-phase: Includes use during specified in-vehicle battery lifetime and also the possible battery reuse (second life in another application like stationary energy storage).*

7) ***Recycling:*** *Includes the entire recycling process of a battery (including collection, transportation, storage, deconstruction and separation/purification for recycling of materials and components).*

To have deeper insights about the most important steps, we concentrated our efforts on mining, cell production and recycling. **Mining** has the highest social and environmental impact of all seven steps. The European market of **cell production** is growing very fast at the moment, as European countries have a large focus on strengthening the battery production in Europe and there is also a strong market pull from the car companies based there, driven by the strong environmental legislation. This and the possibility of improving responsible sourcing by regulating cell production makes this a very important step in the value chain. In order to achieve a circular economy and limit the risk posed by EoL batteries, they must be **recycled**, which is therefore a crucial step in the battery value chain. In our research for the first step 'mining', we evaluated the material flows around the globe and the social and environmental challenges of resource extraction. Our focus on lithium, cobalt, nickel and graphite results from the fact that the development of the LIB market has a large impact on the sourcing of these materials, as they are all crucial for the future of LIBs. Research on copper, also used widely in batteries, is part of the renewable energy sector analysis within this project (Kügerl 2021).

Moving further down the value chain to cell production, we explain the general process for manufacturing batteries. This includes electrode production, battery cell assembly and quality management. We then look at the challenges and opportunities for improvement, particularly at the environmental level.

Finally, we skip to the last step in the cycle, recycling, where we focus on the development of the recycling industry around the globe as more and more batteries reach their end-of-life (EoL) and the technological and environmental challenges related to this.

2.1 Mining and Processing

Batteries need massive amounts of resources, which are distributed around the globe. As mentioned, this paper focuses on the four most critical resources related to the battery value chain: lithium, cobalt, nickel and graphite. To be able to get a better understanding of their origins and the stakeholders involved in their extraction, this chapter lists the countries and companies mainly involved in the production of these minerals.

The following figure illustrates global production, EU import and worldwide reserves of the four selected materials lithium, cobalt, nickel and graphite.

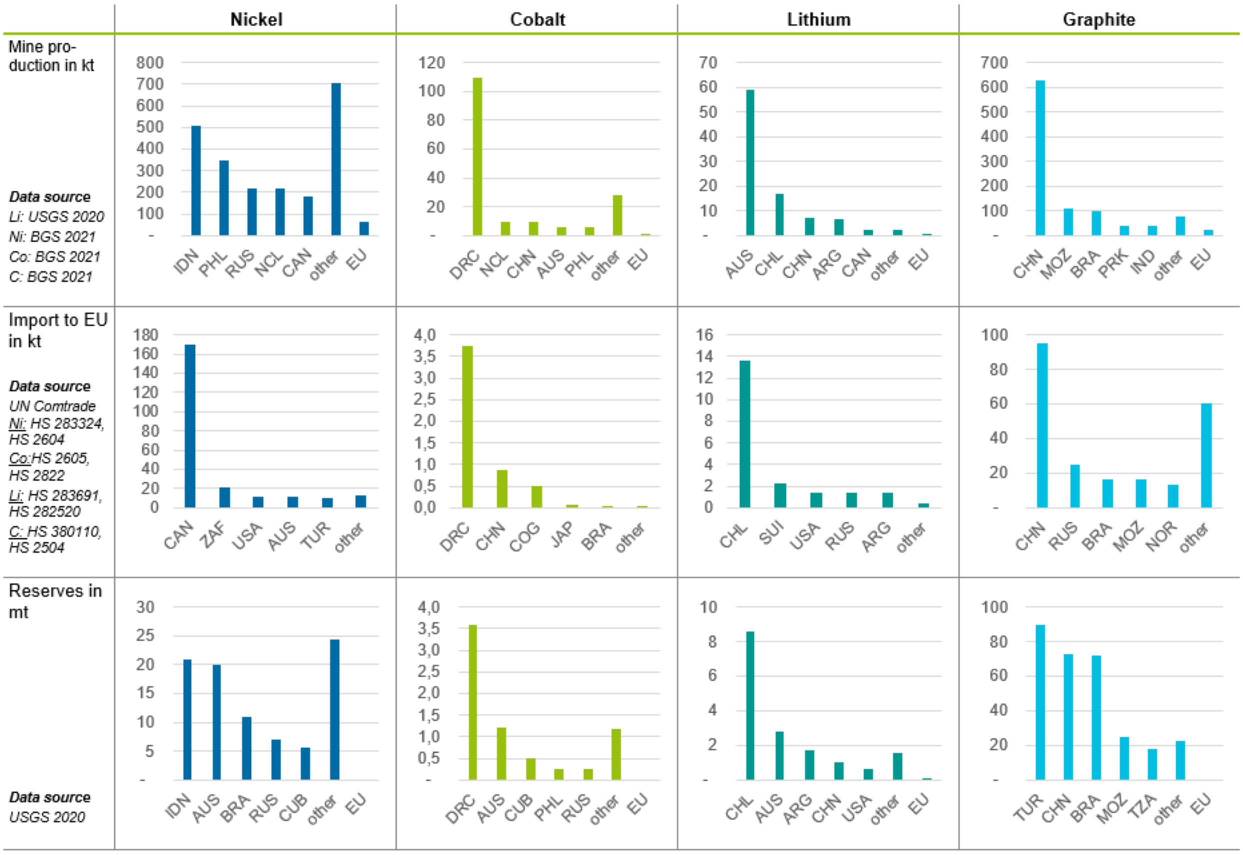


Figure 5: Overview of the four selected raw materials lithium, cobalt, nickel and graphite 1

2.1.1 Lithium

Lithium is essential for LIBs, although it only represents a small percentage of a battery cell's weight (≈ 2 % per cell). Nevertheless, LIBs are already responsible for 57 % of lithium demand (ahead of glass and ceramics, lubricant/grease, metallurgy etc.) (BMI 2020a). In general, the global lithium value chain has not yet been fully established itself, as demand and also production has been rising strongly over the last few years and shifted from South America as the strongest producing region to Australia. An overview of global lithium production is given in Figure 6. While Chile led the primary lithium production market up through 2016, thereafter Australia has become the largest lithium producer in the world. For more information about the challenges of lithium production, see chapter 3.1.1.

[1] All data refers to 2018 sources:
Mine production: Li: (USGS 2020b); Ni, Co, C: (BGS 2021)
Import: All data refers to (UN Comtrade 2021):

- Nickel: HS 283324 Sulphates; of nickel; HS 2604 Nickel ores and concentrates;
- Cobalt: HS 2605 Cobalt ores and concentrates; HS 2822 Cobalt oxides and hydroxides; commercial cobalt oxides;
- Lithium: HS 283691 Carbonates; lithium carbonate; HS 282520 Lithium oxide and hydroxide
- Graphite: HS 380110 Graphite; artificial; HS 2504 Graphite; natural

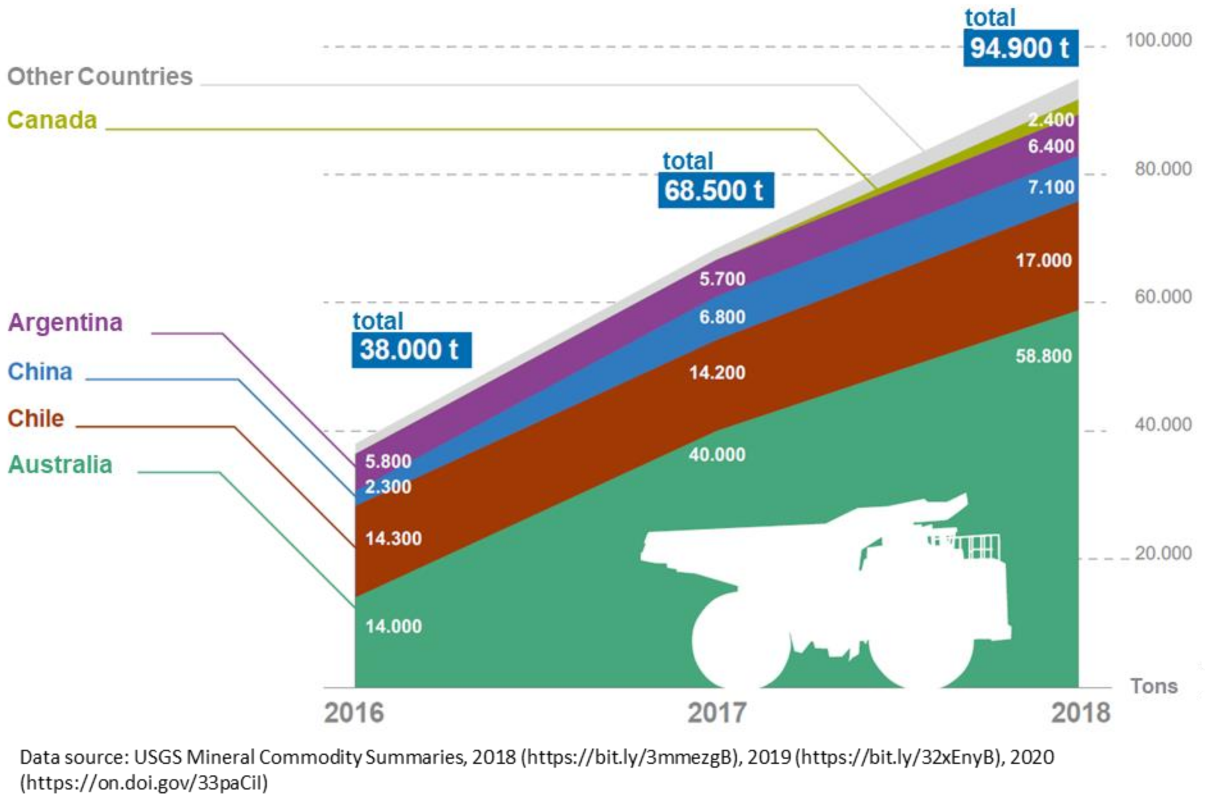


Figure 6: Global primary lithium production (Source: Oeko-Institut 2020)

Currently, the companies with the highest production figures for lithium extraction are, in alphabetical order (Schmidt 2017, BMI 2020a, Miningscout 2018):

Albemarle

Albemarle is based in the USA and has three independent operations for primary lithium. The first one is in Chile. The Salar de Atacama has the largest reserves of lithium in the world; Albemarle is one of the companies which operates a brine mine there since the 1980s. The second operation is in Silver Peak, Nevada, USA, which is brine-based plant operated by Albemarle since the 1960s. The last one is in Australia, where Albemarle attained 49 % share in Talison Lithium in 2014, giving it access to spodumene resources (Greenbushes). Apart from mining, Albemarle also refines lithium in the USA.

GanfengLithium

Jiangxi GanfengLithium is based in China and the world's largest lithium producer in 2020, as other producers did not reach their targeted production capacities (BMI 2020a). It has invested in many lithium mining projects around the world (Argentina, China, Mexico, Australia) and uses different methods to extract lithium from various sources (spodumene, brines, recycling). GangfengLithium and Tianqi are the largest refiners of lithium in the world (USITC 2020).

Livent

Livent, formerly known as FMC Corporation, is based in the USA, but present in many countries, while mining mainly in Argentina and Canada.

SQM

SQM (Sociedad Química y Minera) is a Chilean company and produces lithium hydroxide and lithium carbonate from brine. Like Albemarle, SQM mines in the Salar de Atacama in Chile. Apart from Chile, SQM has also invested in mines in Argentina and Australia (SQM 2018).

Tianqi

Tianqi Lithium is a Chinese company and has the largest lithium production capacities in the world (BMI 2020a). It is involved in Talison Lithium (Australia, Tianqi (51 %) and Albermarle 49 %) and owns the largest LiOH plant in the world in Kwinana, Australia (Gov WA 2019). It is the world's single largest refiner of lithium materials (USITC 2020).

Mineral Resources Limited

Minerals Resource Limited is an Australian company and has the fifth largest lithium production capacities in the world. It produces Lithium out of the Mt Marion mine with an initial capacity of 206 000 tonnes of spodumene concentrate per year. The capacity is being extended to 450 000 tonnes per year (NS Energy 2021).

2.1.1.1 EU Mining Activities:

Today, there is no significant lithium production in the EU27. A mine in Alvarães, Portugal, operated by Mota Soluções Cerâmicas (MCS), only produces a small amount of lithium for ceramics. However, as indicted in Table 2, several projects for lithium production in the EU are planned that shall use different lithium sources.

Table 2: Overview of EU lithium miners in alphabetical order per country (Cornish Lithium 2021; SR 2021; Mining Journal 2019)

Company	Country of planned operation	Type
European Lithium	Austria	spodumene
European Metals	Czech Republic	zinnwaldite
UnLimited	Germany	thermal brines
Vulcan Energy Resources	Germany	thermal brines
Zinnwald Lithium plc	Germany	zinnwaldite
Cornish Lithium	Great Britain	thermal brines
Keliber Oy	Finland	spodumene
Savannah Resources	Portugal	spodumene
Rio Tinto	Serbia	lithium-borate deposit which contains jadarite, a lithium sodium borosilicate mineral
Infinity Lithium	Spain	zinnwaldite

Leading Edge Materials	Sweden	spodumene

Livista Energy plans to refine lithium and produce initially 30 000 t/a in Europe (Livista 2021); for more information, see the corporate website[2].

2.1.2 Cobalt

Cobalt (Co) is part of NMC (lithium nickel manganese cobalt oxide), which is the main cathode material for xEVs (all types of electric vehicles). It increases the conductivity of the cathode material and stabilizes the cathode structure, thereby increasing the cycle life and the power capability of the battery (Li & Lu 2020). Cobalt is a commodity, which is in most cases a by-product of nickel or copper mining[3], although in different concentrations. Therefore, the production of cobalt is also strongly related to production of the other metals. However, an increase in cobalt production could also be achieved by refining the tailings of mines that have not already extracted cobalt due to low market demand or previous technological barriers.

The vast majority of cobalt production occurs in the Democratic Republic of the Congo (DRC), providing over 70 % of worldwide production (see Figure 7). Although artisanal and small-scale mining (ASM) is strongly represented in the media, it is estimated that cobalt production in the year 2020 in the DRC from large-scale mining (LSM) operations rose to a share of over 90 %. ASM extraction of cobalt in the DRC during 2020 provided less than 5 % of the world cobalt supply (BMI 2020b). However, this is unusual and correlated to the low cobalt price and the Corona pandemic. The ratio of ASM compared to LSM in the DRC has been much higher in the past (closer to 25 %) (Mancini et al. 2020).

ASM cobalt production has historically been strongly linked to market demand. Previous trends indicate that, as prices rise in a tighter market, the ASM sector for cobalt increases production to provide the ‘swing supply’ to the market. Although currently cobalt prices are drastically lower than their peak in April 2018, and likewise ASM shares in the market have significantly contracted, this could change with the market demands.

Counteracting this trend, stronger regulations of mining practices are expected to slow ASM reactivity to these market forces. This would in turn limit the ability of ASM to provide a swing supply and perhaps then impact prices (BMI 2020b). Nevertheless, ASM is still very important, as it provides income for a large number of people and at the same time can have a highly negative social and environmental impact.[4]

[2] https://livista.energy/ (15.03.2021)
[3] There is only one mine in Morocco, which produces cobalt as main product. (Shedd et al. 2017).
[4] Cobalt is not itself classified as a conflict mineral. Yet, since artisanal mining accounts for a significant share of all cobalt production in the DRC, it nonetheless carries a number of environmental and social risks (Al Barazi 2017). In light of this and the broader context of cobalt mining in the DRC, cobalt might be classified under the minerals where due diligence along the supply chain is required.

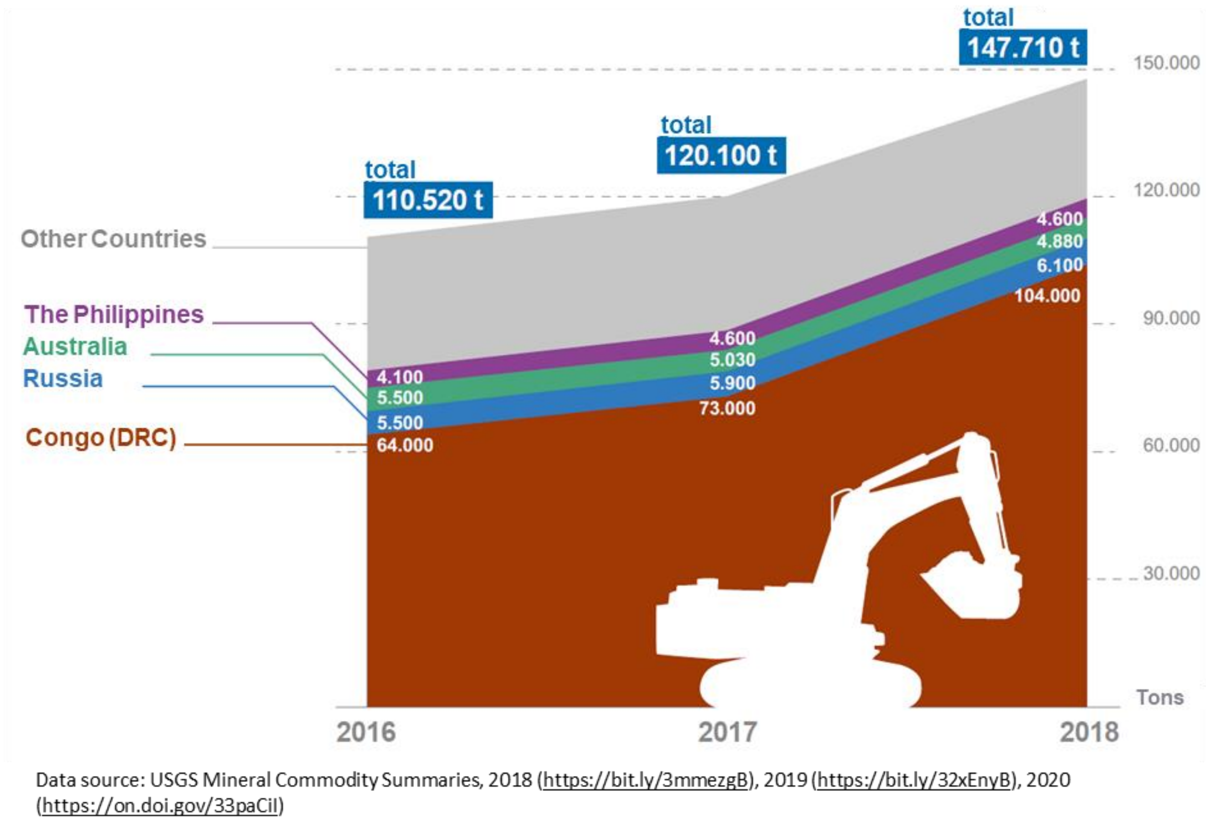


Figure 7: Global primary cobalt production (Source: Oeko-Institut 2020)

There are many companies involved in cobalt production. Currently, the largest are (in alphabetical order):

China Molybdenum

China Molybdenum (China Moly) is based in China and the second largest producer of cobalt (Argus Media 2020). It operates the Tenke Fungurume mine (owns 80 % since 2019), producing copper and cobalt, and it took over the Kisanfu project (95 %, remaining 5 % belong to the DRC government; in development to produce copper and cobalt), both mining projects in the DRC (Reuters 2020a).

Chemaf

Chemaf (Chemical of Africa) is a subsidiary of Shalina Resources, a company operating mainly in the DRC, while their headquarters are in the United Arabic Emirates. It operates several mines producing cobalt in the DRC.

Gécamines

Gécamines (Générale des Carrières et Mines) is an enterprise owned by the DRC government, which is heavily invested in several copper-cobalt mines (Boss, Kolwezi, Lubumbashi Slag Hill, Ruashi) in the DRC (Gecamines 2017). In most cases, however, it is not the main mine operator.

Glencore

Glencore is the largest miner of cobalt in the world. In 2019, it produced about 42 200 t of Co hydroxide in Katanga (DRC), 3 400 t Co metal in Murrin Murrin (Australia) and 700 t Co metal in Nikkelverk (Norway). Mutanda, a large copper-cobalt mine in the DRC, is currently (as of 2020) placed on care and maintenance. All in all, Glencore is responsible for about 25 – 30 % of global cobalt production.

Huayou Cobalt

Huayou Cobalt, based in China, reports that they are the largest cobalt refiner in the world. It has Congo Dongfang International Mining (CDM) as a subsidiary, which has the right of first refusal for the entire ASM cobalt (copper) ore production from Kasulo in the DRC.

Vale

Vale S. A. is a Brazilian mining company operating several large iron and nickel mines around the world, with some of the nickel mines also producing cobalt as a by-product (e.g. in New Caledonia and Canada).

2.1.2.1 EU Mining Activities

Most cobalt from the EU27 is produced in Finland (Statista 2018). Although they do not play a major role in the global cobalt market, the following companies are looking for cobalt in the EU (not necessarily an exhaustive list):

Table 3: Overview of EU27 cobalt miners

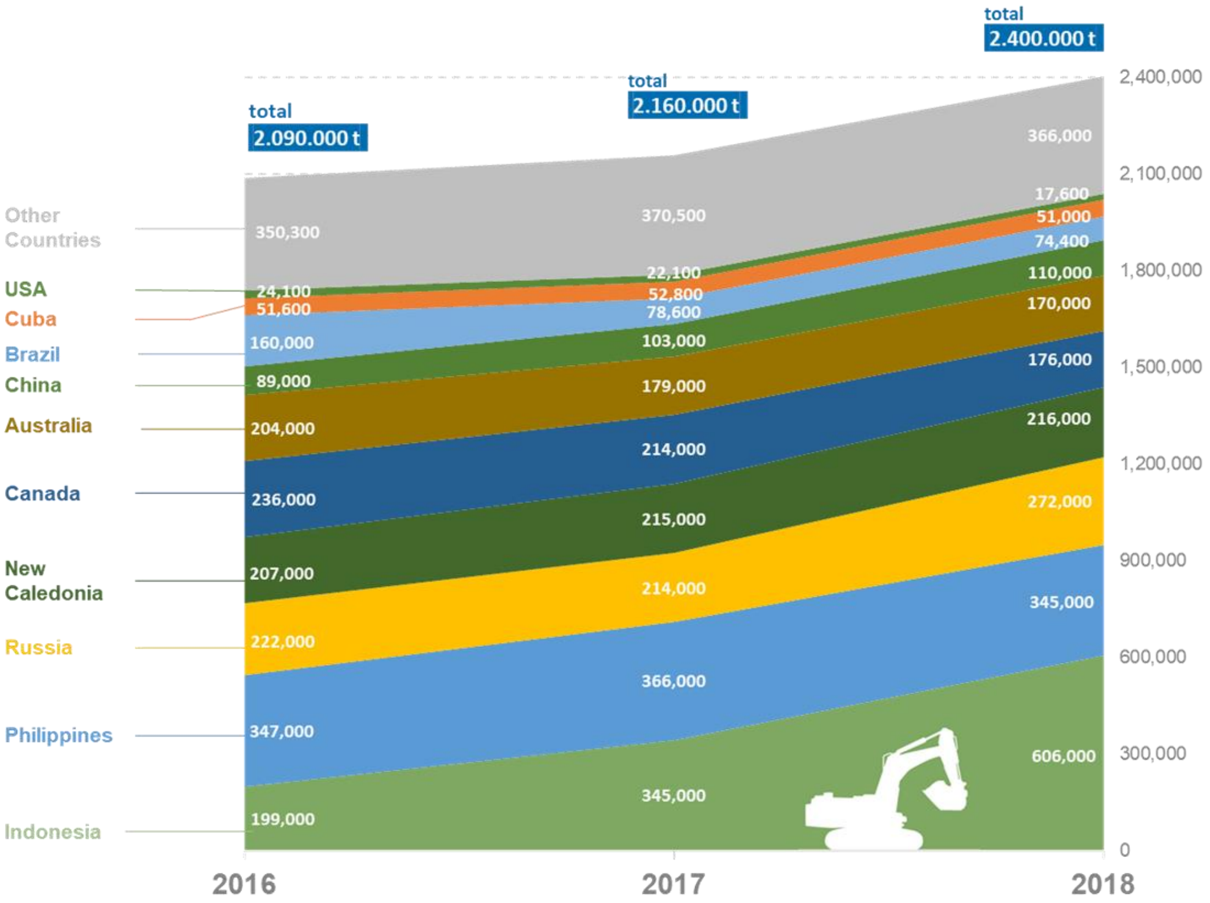
Name	Mining in	Status	Metals
Terrafame Oy	Finland	Producing	Nickel, zinc, cobalt, copper
Eurobattery Minerals	Sweden, Finland, Spain	In development	Nickel, cobalt, copper, rare earth elements
European Cobalt Ltd	Slovakia, Finland	In development	Copper, nickel, cobalt, gold, silver
Talga Resources	Sweden	In development	Copper, cobalt

Umicore refines cobalt in Kokkola, Finland. It is the largest cobalt refinery outside of China (15 000 t/a) (Chemical Engineer 2019).

2.1.3 Nickel

The global production of nickel (Ni) is much more distributed around the world than other battery materials, as can be seen in Figure 8. Since most nickel is used in steel production, LIBs only use a fraction of global nickel production. Other nickel applications relate to defence systems, prompting countries around the world to consider securing their own supply. In general, nickel demand for batteries can be easily covered by the available supply. However, LIBs need nickel with a very high degree of purification, which is only performed in certain countries.

Nickel is used as the most common cathode material for traction batteries, as part of lithium nickel cobalt manganese oxide (NMC). This cathode material comes with different ratios of transition metals (nickel, cobalt and manganese), although many producers tend to prefer high nickel ratios, as they increase the battery's energy density. This also goes along with lower cobalt and manganese ratios.



Data source: USGS Mineral Commodity Summaries, 2018 (https://bit.ly/3mmezgB), 2019 (https://bit.ly/32xEnyB), 2020 (https://on.doi.gov/33paCiI)

Figure 8: Nickel mine production by country in 2018 in tonnes (Source: Oeko-Institut)

There are many companies involved in nickel production. The largest are (in alphabetical order) (McCrae 2018):

Anglo American

Anglo American, with its headquarters in England, mines nickel in two Brazilian mines: Barro Alto and Codemin.

BHP

BHP (Broken Hill Proprietary Company), formerly known as BHP Billiton, and its subsidiary Nickel West are both based in and operate several nickel mines and refineries in Western Australia (BHP 2021). It is an Australian-British commodities group and, together with Vale and Rio Tinto, one of the world's three largest mining companies. BHP was the world's fifth largest nickel producer in 2019 (Statista 2020).

Glencore

Based in Switzerland, Glencore has invested in nickel mines in Canada, New Caledonia and Australia. It refines nickel and cobalt in their refinery Nikkelverk in Norway, which they state is the largest nickel refinery in the western world (Glencore 2021).

Jinchuan

The Jinchuan Group Ltd. is a Chinese resourcing company producing different minerals like nickel, copper, cobalt and others. Jinchuan produced about 150 000 tonnes of Nickel in 2019 and is, therefore, the third biggest nickel producer in the world (Statista 2020).

Nornickel

Nornickel (former Norilsk Nickel) operates some of the largest nickel mines in the world. It is based in Russia but also has operations in Finland and South Africa. In Harjavalta, Finland, it refines about 66 000 t of metals a year (not only nickel, but also copper and platinum group metals) (Nornickel 2021). In 2019, Nornickel was the second largest nickel producer with around 166 thousand tonnes (Statista 2020).

Vale

Vale S. A. is a Brazilian mining company operating several large iron and nickel mines around the world. Its biggest nickel mines are in Canada, but it also operates nickel mines in Indonesia, New Caledonia and Brazil (McCrae 2018). In 2019, Vale was the largest nickel producing company with around 208 000 tonnes (Statista 2020).

2.1.3.1 EU Mining Activities

Production of nickel ore from mining in the EU27, occurring in Finland and Greece, contributed to 2.1 % of the global mine supply in 2019 and totalled 71.8 kt of primary refined nickel (including Class 1 metal[5] and primary nickel sulphate). The entire EU27 intermediate nickel production in 2020 is expected to have increased, to 62 kt, providing 5.7 % of global intermediate nickel supply. Finland produced about 95 % of the EU27's intermediate nickel in 2020, coming from Boliden operations in Harjavalta, Terrafame operations in Talvivaara and the smaller Mondo Minerals operation for crude nickel sulphate in Vuonos (JRC 2021).

The majority of the EU's refined primary nickel production also occurs in Finland, accounting for about 76 % of the 2020 refined output. France, Austria, Belgium and Germany also refine nickel.

Although they do not play a major role on the global nickel market, the companies listed in Table 4 are exploring for and/or producing nickel in the EU. The supply of nickel is also relevant for the defence sector, as mentioned earlier, and, thus, also of major interest for the EU.

Table 4: Overview of EU27 nickel miners

Name	Mining in	Status	Metals
Boliden	Finland	Producing	nickel, copper, gold, platinum, palladium
Mondo Minerals	Finland	Producing	Nickel as part of talc mines

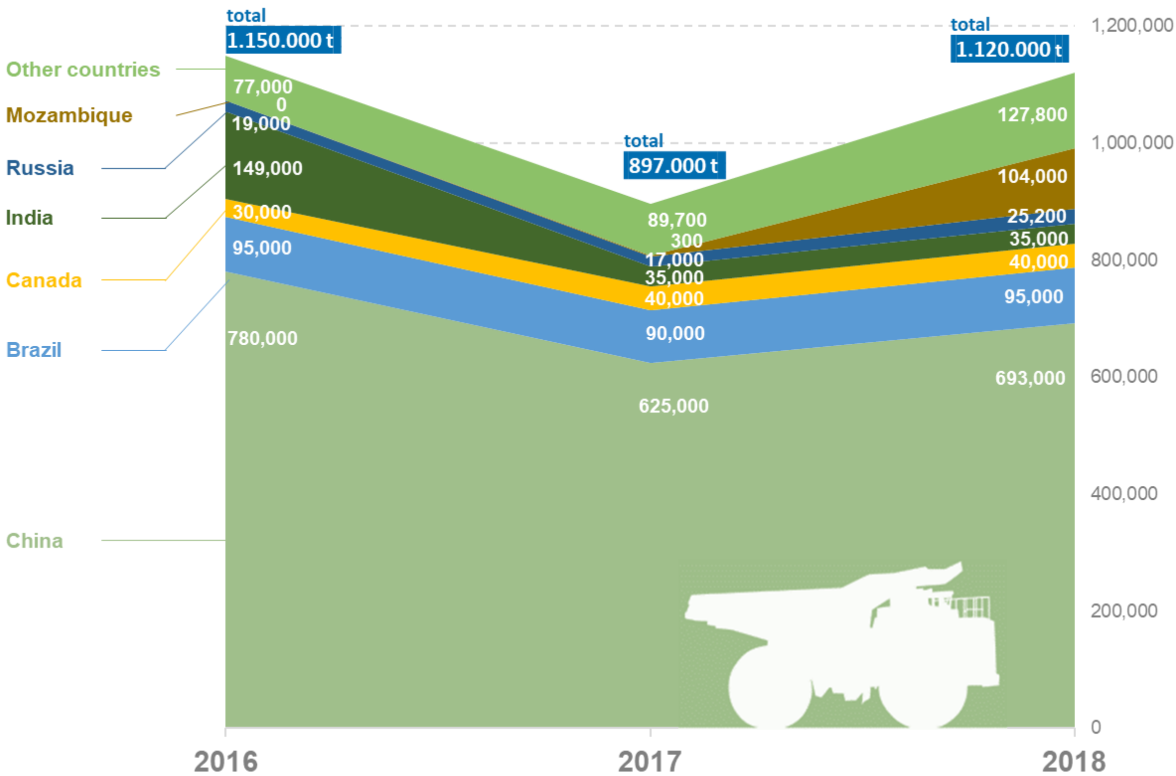
[5] Class 1 nickel products correspond mainly to electrolytic nickel, powders and briquettes with a nickel purity of at least 99.8 %. About 55 % of the total nickel mine production is Class 1. Class 2 resembles mostly nickel products for e.g. steel production with high contents of other metals like iron.

Terrafame Oy	Finland	Producing	Nickel, zinc, cobalt, copper
Eurobattery Minerals	Sweden, Finland, Spain	In development	Nickel, cobalt, copper, rare earth elements
European Cobalt Ltd	Slovakia, Finland	In development	Copper, nickel, cobalt, gold, silver

2.1.4 Graphite

LIBs typically use graphite as their anode material. Natural graphite (NG) can either be mined in open pits or underground. Its counterpart, synthetic graphite (SG), can be produced by heating coke or other carbon-based precursors. Both graphite forms must then be processed further before they can be used as anode materials. The different origins of NG and SG contribute to differences in their post-processing purity and their electrochemical properties.

Mining operations for NG are mostly found in China, where over 60 % of the world's NG was produced in 2019 (see Figure 9; USGS 2020). Other countries have been increasing their NG mining; in 2018, Mozambique mined the second largest amount of natural graphite in the world, contributing about 9 % of the worldwide market share, although their production is refined in China as well (Pillot 2019).



Data source: USGS Mineral Commodity Summaries, 2018 (https://bit.ly/3mmezgB), 2019 (https://bit.ly/32xEnyB), 2020 (https://on.doi.gov/33paCiI)

Figure 9: Natural graphite mine production by country in 2016, 2017 and 2018 in tonnes (Source: Oeko-Institut)

NG is produced by many companies, most of them with connections to China. Their market shares and names are depicted in Figure 10.

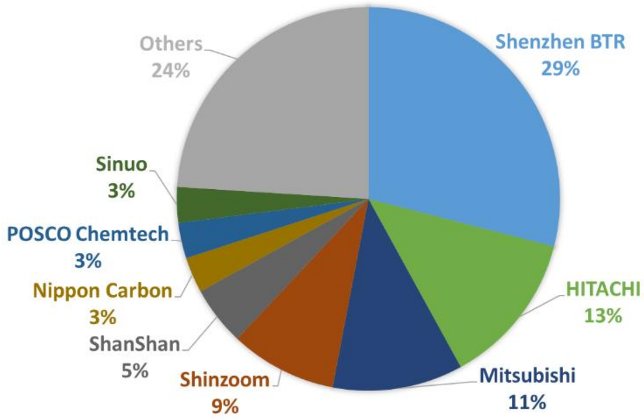


Figure 10: Corporate world market shares for natural graphite production in 2018. Data from (Pillot 2019).

SG production, while more expensive than NG, is expected to continue to grow for use in batteries, as it has a more predictable quality range and higher level of purity than NG (Schmuch et al. 2018). Already in 2018, SG had approximately 56 % of the market share for LIB anode materials, followed by 35 % for NG and the market's remaining 9 % for amorphous carbon, silicon composites and lithium titanate (Pillot 2019).

Several NG mining companies also produce SG. The ones with the highest market share are depicted in Figure 11.

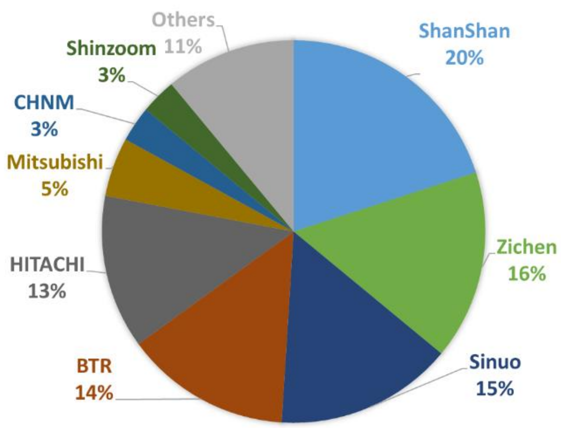


Figure 11: Corporate world market shares for synthetic graphite production in 2018. Data from (Pillot 2019).

2.1.4.1 European Mining Activities

Natural graphite is mined in several European countries, as can be seen in Table 5. However, as illustrated before, there are no major European companies refining natural graphite for anode materials.

Table 5: Overview of European natural graphite miners

Name	Mining in	Status
Graphit Kropfmühl (Dutch Advanced Metallurgical Group N.V. (AMG))	Germany	Producing
Grafitbergbau Kaisersberg	Austria	Producing
Leading Edge Materials	Sweden	Producing
Mineral Commodities Ltd (MRC)	Norway	Producing
Skaland Graphite AS	Norway	Producing
Talga Resources	Sweden	Producing
Zavalyevskiy Graphite[6]	Ukraine	Producing

The only synthetic graphite production in Europe to our knowledge, is SGL Carbon, a German company with sites around the world. SGL Carbon produces not only synthetic graphite, but also other advanced carbon products (SGL 2021).

2.2 Cell Production

Current battery cell production is dominated by Asian countries. An overview of the companies with the highest share (in US dollars) of the global battery pack market is shown in Figure 12. There the diversity of the market with the high number of companies becomes visible. The largest is LG, a South Korean chemical company, followed by Samsung SDI, also from South Korea. Tesla in third place is mainly a car manufacturer based in the US, but also produces LIBs, mainly in collaboration with Panasonic, the company with the fourth highest market share. CATL is also one of the largest battery cell manufacturers, based in China and expanding massively. However, the battery market is very dynamic and constantly changing, with new battery cell factories being planned, built and starting production all the time. Therefore, and for the reason that these figures refer to 2018, the order should be taken with caution.

[6] operating the Zavalye graphite field, the largest mine (flake graphite) in Europe (DERA & ICMNR 2020)

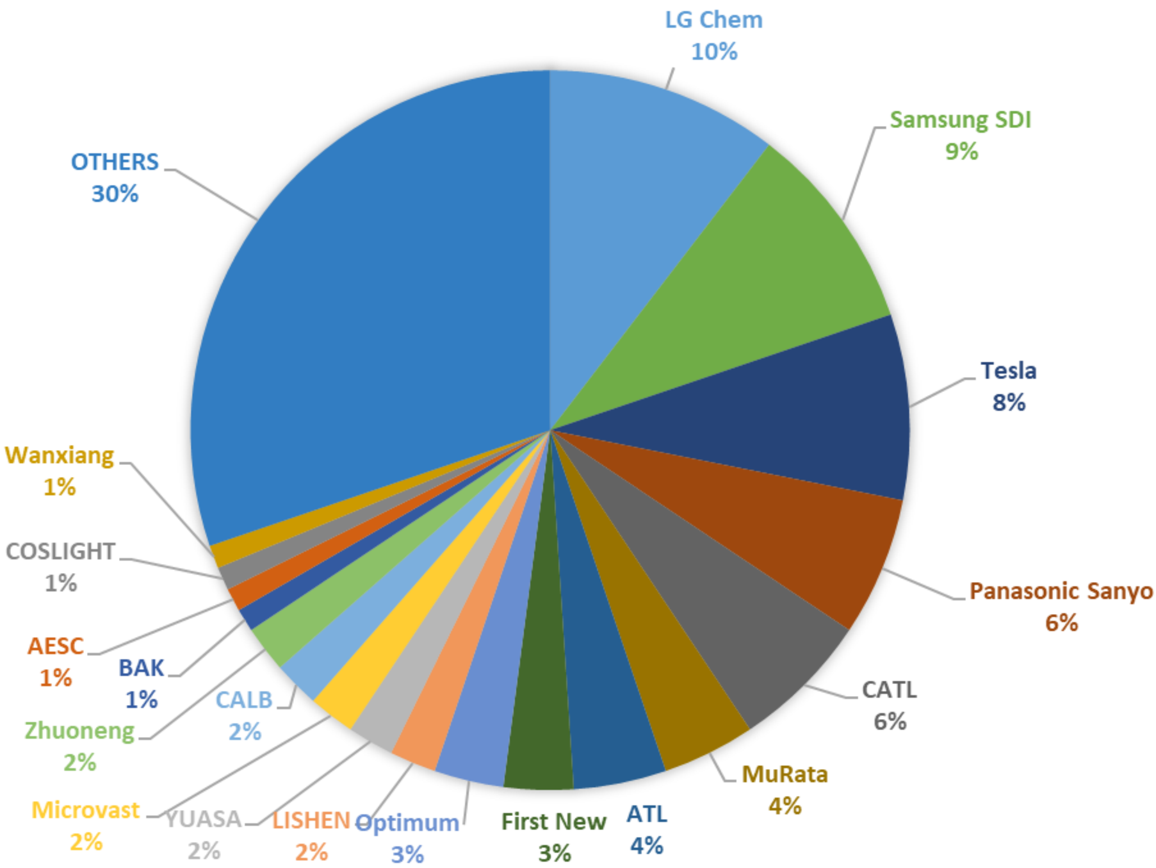


Figure 12: Overview over the companies and their global market share of the LIB pack market (Pillot 2019)

Although the battery market is currently dominated by Asian countries, the battery production landscape in Europe is growing, too, as can be noted in Figure 13. This overview indicates the production sites already built and producing battery cells (dark blue arrows with bold letters) and the announcements for new production sites or plants which have not started production yet (light blue arrows). Most companies already producing battery cells (not only packs, where different cells are put together) have their plants in Eastern Europe (LG Chem, Magna Energy Storage, Samsung SDI and SK Innovation). Additionally, there are Envision AESC producing cells in Great Britain, Blue Solutions in France and Leclanché in Germany. There are many more plants to come, especially in Germany. It is difficult to keep up with the announcements of new battery cell plants, e.g. from Volkswagen[7], some of which are not yet on the map.

[7] Six battery cell plants in Europe with up to 40 GWh/a production capacity (VW 2021)

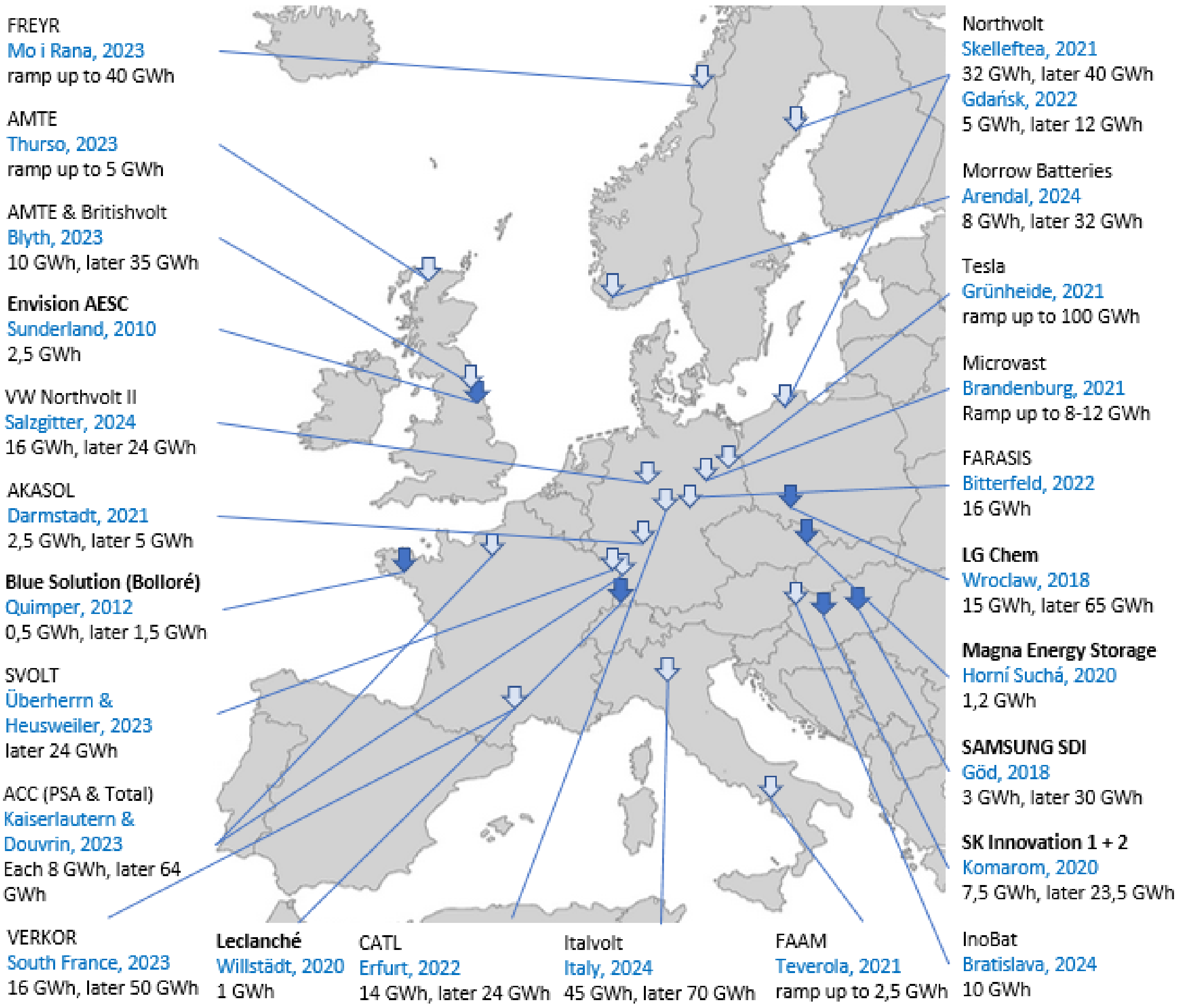


Figure 13: Overview of battery cell plants announced in Europe (T&E 2021; Zenn 2021)

In order to provide a better overview of the companies involved in battery cell production in Europe, the following sections list selected cell manufacturers in alphabetical order, divided into those already producing and those with plants under construction/planning, and describe them in more detail.

2.2.1 Companies with producing European battery plants

Envision AESC

AESC used to belong to Nissan but was since sold to the Envision group in 2019. It has three plants on three continents that annually produce batteries totalling 7.5 GWh. Thereof 3.0 GWh in United States (Smyrna), 2.6 GWh in Japan (Kanagawa), and 1.9 GWh in UK (Sunderland) (UK Motor1 2020).

Leclanché

The Swiss company Leclanché runs a facility based in Willstädt (Germany). The company aims to expand capacity from 0.05 GWh in 2015 to 1 GWh in the future (Lebedeva et al. 2016).

LG Chem

LG Chem, one of the biggest LIB cell producers in the world, is based in South Korea. Apart from its production sites there, it operates a battery plant in Wroclaw (Poland) with 15 GWh production capacity and the plan to scale up to 65 GWh. According to its website: *LG Chem currently supplies 13 of the 20 major car brands, including Volkswagen, Renault, General Motors and Hyundai. The Group has presently five battery plants in South Korea, China, the United States and Poland with a total capacity of 70 GWh. In total, the South Koreans plan to invest around 3 trillion won (about 2.25 billion euros) in battery plants this year, increasing capacity to 100 GWh before the end of the year* (Electrive.com 2020c).

Magna Energy Storage (MES)

Magna Energy Storage (MES) operates a battery plant in Horní Suchá (Czech Republic), which has the production capacity of 1.2 GWh per year (CzechTrade 2020).

Samsung SDI

Samsung SDI is based in South Korea and is one of the largest battery cell manufacturers in the world. Additionally, it has cell production in Göd (Hungary) with production capacity of 4 million battery cells per month. At the end of 2018, Samsung line 1 entered into operation; lines 2-4 began operating between March and September 2019. The construction of a second plant in Göd is underway, with operations scheduled to begin in 2021 and an expected annual capacity of 12 million cells in four production lines (THELEC 2020a, THELEC 2020b).

SK Innovation

SK Innovation is based in South Korea. Apart from LIB production, its main focus is the exploration and production of crude oil and natural gas. SK Innovation built a battery factory in Komarom (Hungary), which started production in 2020 with an annual capacity of 7.5 GWh; a second battery factory with a capacity of 9,8 GWh (Yonhap 2020) is being built by 2022 and a third factory is planned (Battery-News 2020). Later, the second plant will likely be extended to a capacity of 16 GWh (Reuters 2020b).

2.2.2 Companies with planned or under construction European battery plants

AMTE

The common project of the two start-ups Britishvolt and AMTE Power is a production facility in St. Athan, Wales (UK) for batteries for electric cars. The site's first development stage should be completed by 2023 with a capacity of 1-5 GWh per year and will be further extended until it reaches the intended final capacity of 30-35 GWh (Electrive.com 2020a).

Automotive Cells Company (ACC)

The Automotive Cells Company (ACC) is a joint venture of PSA/Opel and Total/Saft. It has planned two giga factories in Kaiserslautern (Germany) and Douvrin (France), with production starting in 2023. The total planned production capacity of both plants combined is 48 GWh by 2030. The goals are a low carbon footprint, 95 % recyclability, ethical supply chain and green factories using renewable energy sources (ACC 2021).

CATL

Contemporary Amperex Technology Co. Limited (CATL) is one of the largest producers of LIBs for electric vehicles (EVs) in the world and based in China. Guangdong Brunp, a LIB recycler, is a subsidiary. CATL was the first producer to announce a LIB factory in Germany, which is now being built (initially with 14 GWh and up to 24 GWh in a later expansion stage) near Erfurt (Electrive.com 2019, CATL 2020).

Farasis

Frarasis is planning a plant in Bitterfeld-Wolfen, Sachsen-Anhalt (Germany). In 2022, the plant shall begin with producing 6 GWh and an extension to 10 GWh has already be announced (Electrive.net 2019). Daimler bought shares of Farasis to secure battery cells for their BEV production (Farasis 2020).

Freyr

According to its website, FREYR is a Norwegian LIB company that develops, finances, constructs and operates LIB facilities. It plans to produce 'green battery cells' that are made using power from its own wind park and other energy sources. It is developing a pilot plant that will be 'scalable and modularized' with a '2-25 GWh fast-track facility and a 32 GWh giga-factory' (Freyr 2021).

InoBat

InoBat is building a pilot-scale battery cell production plant (100 MWh/a) in Košice (Slovakia) with the plan to scale production with another plant up to 10 GWh in 2024 (Electrive.com 2020b).

Microvast

Microvast, founded in Texas (USA) has its European headquarters in Ludwigsfelde (Germany) and has announced a battery plant to be built in Brandenburg (Germany) (Electrive.com 2020d).

Morrow Batteries

The Norwegian company Morrow Batteries is developing a battery cell factory in Arendal in the southern Norwegian region of Agder. In 2024, the first stage of 8 GWh will be completed and further developed in three further stages of 8 GWh each, to a final capacity of 32 GWh capacity (Electrive.com 2020e).

Northvolt

Northvolt is a start-up battery producer based in Sweden, which is building a battery factory in Skellefteå (Northvolt Ett, northern Sweden). According to its website, "large-scale manufacturing will commence in 2021 and annual capacity will ramp up to at least 32 GWh by 2024, with the potential to expand to 40 GWh in the future." (Northvolt 2021A) Currently there is pilot scale production of 350 MWh/a.

Northvolt has a joint venture with VW, called Northvolt Zwei, to establish "a battery factory in Salzgitter, Germany. Start of construction is slated for 2021 and start of operations scheduled for early 2024. Initial annual output will be 16 GWh" (Northvolt 2021A). Northvolt has a "Commitment to Sustainability", where it states, among other things, that it will produce "green" battery cells using 100% renewable energy (Northvolt 2021B).

Svolt

Svolt, a Chinese battery producer, plans a plant in Überherrn (Germany). It will produce 24 GWh in the final stage, with production starting in 2023. Among other things, SVOLT is the first company planning to bring a battery cell with a layered transition metal oxide cathode with a high nickel content and without cobalt to mass production readiness.

In future, all SVOLT products produced in the EU factories will be with 100 percent "green electricity". SVOLT is currently also examining the possibility of using electric, carbon-neutral shuttle trucks for transport between the plants (Electrive.com 2020f).

Tesla

Tesla is the most valuable car company on the stock market and only produces BEVs. Furthermore, it is one of the few car companies producing its own battery cells. Tesla made a partnership with Panasonic to build the largest battery factory in the world in Nevada (USA. It is currently building a car factory in Grünheide (Germany), which shall also produce battery cells in the future.

Volkswagen

Volkswagen (VW) is one of the largest car companies in the world. It plans to sell at least 70 % BEVs compared to the whole fleet by 2030 (Electrive.net 2021). It does not produce its own battery cells yet, but its joint venture Northvolt Zwei (50/50 Northvolt and Volkswagen AG) has planned to produce batteries in Salzgitter (Germany) (AI 2020). Furthermore, VW is part of Drive Sustainability (see chapter 4.2.1).

2.3 Recycling

Lithium-ion battery (LIB) disposal is in part regulated under various existing and upcoming regulations (e.g. the Basel Convention, the EU's updated Battery Directive, etc.). Proper battery disposal is generally motivated by initiatives to protect people and the environment and to keep resources within countries by supporting a circular economy. Consequently, battery recycling is the preferred method to manage end-of-life (EoL) batteries. Apart from the fact that recycling is the only viable waste treatment option for LIBs due to their intrinsic danger, the strategic importance of LIB recycling taking place in the EU can be summarised in the following four points.

Battery recycling in the EU:

provides the EU with key materials for electromobility through environmentally friendly, socially acceptable and energy and cost-efficient processes;

reduces EU dependence on non-European sources for materials for battery cells and the mobility sector in general;

establishes and develops a new high-tech branch within the EU circular economy, with significant EU actors providing innovation and investment, whereby creating jobs and turnover by extending the value chain beyond the use phase; and

transfers knowledge and recycling plant technology for LIBs into the EU.

Battery recycling initiatives exist worldwide, often alongside battery cell production to help manage production waste. The vast majority of LIB recycling currently occurs in China and other Asian countries. Some plants, however, have already been established in the EU.

2.3.1 Battery Recycling Plants in the EU

The EU27 currently has several battery recycling companies that are working on improving their battery recycling processes, in some cases in conjunction with private-sector or university partners. These initiatives are largely triggered by the expected market growth of LIBs in the mobility sector and foresee expanding their future processing capacities as demand increases. Some of the recycling routes already implemented on an industrial scale are capable of recovering steel, copper, nickel and cobalt compounds from LIB modules with a yield of at least 90 %. Currently, research and development activities for recycling LIBs mainly target optimising yields, recovering lithium compounds, and separating and using graphite (Buchert et al. 2020).

The following list (Table 6) of EU27 battery recyclers has been sorted by their currently reported LIB recycling capacities.

Table 6: Recycling companies for LIBs in the EU27

Name	Country	Capacity of LIB and LIB production waste recycling
Umicore	Belgium	7 000 t/a
Nickelhütte Aue	Germany	3 000 t/a
Accurec	Germany	2 500 t/a
Redux	Germany	2 000 t/a
Volkswagen	Germany	1 200 t/a
EDI (Euro Dieuze Industrie), subsidiary of Veolia	France	1 000 t/a
AkkuSer	Finland	n.a.
Duesenfeld	Germany	n.a.
Promesa	Germany	n.a.
SNAM	France	n.a.
TES-AMM (formerly “Recupyl”)	France	n.a.
Ute Vilomara	Spain	n.a.

Companies planning lithium-containing battery recycling plants in Europe:

- Primobius (Hilchenbach, Germany; Joint Venture of SMS and Neometals)
- BASF (Schwarzheide, Germany)
- Northvolt (Skellleftea, Sweden (large plant); and Germany together with VW)
- Fortum (Finland)
- Norsk Hydro + Northvolt in Fredrikstad, Norway (start building in 2021, 8 000 t/a, pilot plant, Euwid 17.11.2020)

2.3.2 Battery Recycling Plants outside of the EU

Countries with a large battery industry typically need a battery recycling industry to manage battery production scraps. It is therefore understandable that where battery production is strongest – in China, Japan and South Korea – the battery recycling industry is more developed.

The major recycling companies outside the EU are listed below and categorised by their recycling capacities:

Processing over 1 000 tonnes per annum (t/a) of batteries and battery production waste (sorted by country and alphabet):

- Brunp (China)
- Ganzhou Highpower (China)
- GEM (China)

- Huayou Cobalt (China)
- Dowa (Japan)
- Kyoei Seiko (Japan)
- SungEel (South Korea)
- Li-Cycle Corp (US)

Pilot scale (processing <1 000 t/a) (sorted by country and alphabet)

- Guanghua (China)
- Telerecycle (China)
- JX Nippon (Japan)
- Kobar (South Korea)
- Retriev (US)

The battery recycling industry needs to keep up with the fast growth of battery production, making recycling a very dynamic market. Challenges for the LIB recycling industry are elaborated in chapter 3.3.

3 Challenges

The production of LIBs (lithium-ion batteries) is growing fast. Connected to this strong growth, there are several environmental, social and regulatory challenges. Mining and mineral processing of battery materials are frequently associated with environmental and social issues. This could be even aggravated by the strong market growth and the related demand for battery resources. Moreover, framework conditions and regulation may be missing that could otherwise offer incentives for battery production in more sustainable ways. Closing material loops with recycling will not be possible in the short to mid-term or even long-term. However, the course for recycling must be set now to provide the required capacities in the future. Up to now, the EU's environmental laws do not fully cover several social and environmental risks in the battery supply chain:

- no transparency on sourcing raw materials;
- high energy consumption related to GHG emissions during production;
- potentials for higher collection rates and increased recycling targets of EoL batteries; and
- untapped potentials for offsetting environmental impacts of battery life cycles.

To tackle these major challenges, we again focus on the three major impacts of the battery value chain: the mining of battery resources, the production of battery cells and their recycling.

3.1 Mining and Processing

The **RE-SOURCING Project** will focus on **lithium, cobalt, nickel** and **graphite** mining and processing. In particular, there are challenges with:

Lithium:

- Brines: Water consumption in arid region and dust emissions, both leading to local conflicts; lack of good governance
- Hard rock mining: Mining of spodumene in open pits, related to heavy metal pollution and acid mine drainage (AMD) potential with energy intensive processing

Cobalt:

- LSM: Environmental challenges related to (open pit) mining in general, corruption, often challenging working conditions in countries with low regulations, AMD potential, heavy metal pollution
- ASM: risk of child labour and bad working conditions in general, no environmental regulations in place (post closure treatment etc.)

Nickel:

- Approximately equal shares of sulphide and lateritic deposits
- Lateritic deposits found in tropical areas with high biodiversity and vegetation, mined in open cut
- Special challenges: AMD, high energy consumption + deep-sea disposal

Graphite:

- Natural graphite (NG): purification with acids
- Synthetic graphite (SG): high energy consumption during production (>2 500 °C necessary)

Mining is always connected to a disturbance of the environment, potentially leading to the destruction or fragmentation of natural habitats. Moreover, the resettlement of local populations to work at the mines often leads to social tensions. However, there are unique challenges connected to every mineral as well as each country and site it is extracted from. In this paper, we focus on the four most critical materials in a battery – lithium, cobalt, nickel and graphite (natural and synthetic) – and sum up the most important environmental and social impacts.

Deep sea mining might be a relevant future source for minerals, e.g. for cobalt. As deep-sea mining is an overarching issue in the RE-SOURCING project, it is analysed in a separate RE-SOURCING briefing document and not be addressed in this State of Play document in the mobility sector.

3.1.1 Lithium

Lithium (Li) has entered the spotlight as the key element used in the powerful and lightweight lithium-ion battery (LIB). Global demand for lithium in mobility applications could increase to 240 000 tonnes by 2030 and up to 1.1 million tonnes by 2050 if the goals of the Paris Climate Agreement are to be met (Buchert et al. 2019).

Although lithium is found in very low concentrations in seawater, it is more cost and time efficient to mine it from either hard rock (e.g. spodumene) or continental brines. Chile has the Earth's largest lithium reserves (about 50 % of worldwide estimates) in its salt flats within the arid 'Lithium triangle', an area covering parts of Chile, Bolivia and Argentina. Most hard-rock extraction of lithium occurs in Australia, which is estimated to have over 20 % of worldwide reserves (USGS 2021, Agusdinata et al. 2018).

The environmental and social issues associated with brine mining for lithium mainly concern water scarcity and pollution resulting from the mining and refining processes. In traditional brine mining, the sun evaporates the water out of salty water (i.e. brine) that is brought to the Earth's surface. When this water that would otherwise have remained in underground reservoirs is lost in an arid region to evaporation, the water losses can have significant environmental and social impacts (Rodrigo et al. 2009). Another challenge is the missing good governance in some regions, including parts of South America, where mining companies are accused of corruption (Deutsche Welle 2018, Transparency 2021b).

Challenges with hard-rock mining for lithium mirror issues for other hard-rock minerals. Pollution – also a risk for all other forms of mining – can result from destruction of the surface environment and habitats as well as from disposal of wastes generated in mining and processing, among other issues. In particular, ore processing and lithium oxide extraction produce wet wastes, called 'tailings', which often contain toxic concentrations of metals or other chemicals. Tailings must be properly stored to prevent leaks and environmental contamination, e.g. to ensure a tailings facility dam cannot break or to prevent chemicals from seeping into groundwater (Dolega et al. 2020).

Hard-rock mining in Australia occurs in rather remote areas. While this means that the physical impact of the mine is not as noticeable to the general population, for the workers in the mine, being removed from a larger social environment can create social challenges. Mine workers are often absent from their families for extended time periods. Other social impacts arise in relation to the exact mine location as some are near sites important to aboriginal communities. These conflicts must be negotiated to ensure a social balance (Dolega et al. 2020).

Also contributing to the environmental impacts of lithium production, lithium processing from ore or brine concentrates requires high energy consumption in addition to the high amounts of energy needed for extraction in hard-rock mining. Determining the exact environmental footprint of lithium depends largely on the energy sources that are used (e.g. from coal, fossil fuels or renewable sources like wind) (Dolega et al. 2020).

Overall, initiatives to reduce the social and environmental impacts of lithium extraction and processing are in place and can continue to be expanded and improved so that lithium can be safely brought to the market. In particular, the amount and sources of energy needed to extract and process lithium need to be considered in any detailed assessment of the mineral. Since lithium's unique properties do not easily allow substitution in batteries, expansion of recycling initiatives could improve the overall social and environmental footprint that lithium leaves (Dolega et al. 2020).

3.1.2 Cobalt

Cobalt has gained attention in recent years since it is used in Li-ion batteries. While Li-ion batteries today are the main application for cobalt, other fields are also important. Cobalt is used in a variety of superalloys and as an alloying element in tool steel. Other important applications are in the pigment industry and the use of cobalt as a catalyst in the petrochemical industry. Most of the applications show significant growth rates, although the market for lithium-ion batteries is growing about twice as fast (BGR 2020).

Compared to other commodities, the metal has a very monopolistic supply structure regarding production countries, as described in chapter 2.1.2. The majority of cobalt was produced in the Democratic Republic of the Congo (DRC), amounting for more than 70 % of global supply. The rest of cobalt production is distributed among a number of countries, with Australia and Russia being the most important (USGS 2020).

Cobalt is mined mainly in large operations as a by-product of copper and nickel production. To date, only one modern, large-scale mining operation (Bou-Azzer, Morocco) extracts cobalt as its main product, accounting for about 1.4 % of world production (Shedd et al. 2017). A significant portion of the production in the DRC is extracted by artisanal and small-scale miners (ASM) as discussed in chapter 2.1.1. (Al Barazi et al. 2018).

ASM involves the extraction of ores with minimal or no mechanization, which is often part of the informal job sector (Hentschel et al. 2003). Since small-scale mining is so labour intensive, it generates many more jobs than large scale industrial mining. It is estimated that between 100 000 and 200 000 people are involved in the ASM sector in the DRC depending on the cobalt prices (BGR 2020). In contrast to ASM, Glencore, the largest cobalt miner, only employs ca. 15 000 workers including subcontractors in all its DRC operations (IGU 2018). ASM is often associated with informality, insufficient occupational safety standards that cause many accidents, long-term health problems of workers, and, most importantly, it is often linked to child labour (Schüler et al. 2018, Tsurokawa et al. 2011). Nonetheless, the sector is an important source of income and livelihood for the local population.

Regarding environmental impacts, cobalt mining is associated with the general risks of metal mining, such as disturbance of land areas, dust pollution, habitat fragmentation etc. (Dolega et al. 2016). Since most cobalt-containing deposits are sulfidic, acid mine drainage (AMD) can pose a risk. AMD occurs when sulphide minerals present in ore, tailings or waste rock are exposed to oxygen and water, causing a chemical reaction that produces sulfuric acid. The acid in turn can dissolve heavy metals, polluting water and soil (Dolega et al. 2016). Some copper-cobalt ores from the Copperbelt in Central Africa are associated with elevated levels of the radioactive element uranium (Al Barazi et al. 2018, Tsurukawa et al. 2011). Attempts to reduce the negative impacts of cobalt mining in the DRC also often fail due to corruption, as the DRC has one of the highest corruption rates in the world (Transparency 2021a).

3.1.3 Nickel

Nickel has gained attention in the last years for its use as one element in cathode materials for Li-ion batteries. Moreover, there is a trend towards nickel-rich cathode materials. Although still mainly used in the steel industry and for alloys, batteries become increasingly more important. Currently, demand for nickel is mainly driven by stainless steel, which covers 74 % of demand, followed by alloys (21 %) and batteries (5 %) (Azevedo et al. 2020).

Global primary nickel production is well diversified. In the last years, Indonesia has become the largest nickel supplier, producing more than 600 000 tonnes and representing ca. 25 % of global production, followed by the Philippines with more than 345 000 tonnes and covering 14 % of output. Other large supplier nations are Russia and New Caledonia, respectively producing 272 000 tonnes (11%) and 216 000 tonnes (9%) (see Figure 8).

Nickel is extracted from sulphide and lateritic deposits, with approximately equal market shares (Buchert et al. 2017). In the past, global production was dominated by sulphide ore mining, with an increasing shift towards lateritic deposits (Mudd 2009). Nickel sulphide ores are formed by volcanic and hydrothermal processes and are often associated with copper, cobalt and sometimes platinum group metals (PGMs) or gold. Sulphide deposits are mined both in open cut and underground mines. Mining is followed by concentration via flotation, smelting of concentrates and refining (Mudd 2009). The potential for AMD generation when mining nickel sulphide deposits is high (Dehoust et al. 2020). This is especially relevant for the post-closure period of mines, which has been often neglected in the past and can lead to immense problems without any responsible party to address.

Lateritic nickel deposits are formed by weathering of ultramafic rocks. Since weathering is a key component in their genesis, they are mainly located in tropical areas with high temperatures and rainfall (Mudd 2010). Accordingly, the deposits are in areas with high biodiversity and dense vegetation. Laterite deposits are always mined in open cut mines since the ore deposits are shallow and spread over large areas. Mining and beneficiation are followed by high pressure acid leaching, where the mined nickel ore is leached with sulfuric acid under high pressure and high temperatures. Then the metal-rich solution goes through a hydrometallurgical solvent extraction. Afterwards, either metal or nickel hydroxide or sulphide is produced. Cobalt is extracted as a by-product in all lateritic nickel mines (Mudd 2009).

The energy required to produce one tonne of metal from laterites is between 2.5 and 5 times higher than producing it from sulphides. Greenhouse gas emissions from laterite deposits range between 25 and 46 tonnes of CO_2 per tonne of primary metal. In contrast, sulphide ore mining results in only 10 tonnes of CO_2 per tonne of primary metal (Mudd 2009, Mudd 2010).

In terms of environmental impacts in general, nickel, like cobalt, is associated with the wide-ranging risks of metal mining, such as land disturbance, dust pollution, habitat fragmentation, heavy metal pollution, etc. (Dolega et al. 2016). A large risk comes from potential disposal of tailings and other waste products into the sea, especially as happens in Indonesia and Papua New Guinea (Kwong et al. 2019).

In some of the countries where Ni is mainly produced, such as the Philippines or Indonesia, corruption is a major problem (Transparency 2021b), which means that even when control mechanisms are in place, they are sometimes circumvented through bribery.

3.1.4 Graphite

Lithium-ion batteries (LIB) mainly use carbon-based anode materials, in particular graphite, because these materials are associated with both a long cycle life and outstanding electrochemical properties such as high energy density and efficiency (Dolega et al. 2020). Additionally, producing carbon anodes is rather cheap per energy content compared to other alternatives like lithium titanium oxide (LTO) (Xu et al. 2017). Two types of graphite can be used for battery anode production: natural graphite (NG) that is mined and then processed and refined, and synthetic graphite (SG) that is created using a carbon-based feedstock and then further processed.

The inert material graphite is not toxic to humans nor to the natural environment but producing and processing it into forms suitable for use in batteries generates environmental, health and safety issues (USGS 2017). SG production, which mainly takes place in China, poses environmental challenges due to its high energy consumption and associated greenhouse gas emissions. It involves heating a carbon source to above 2 500°C and maintaining these temperature for several days (Gomez-Martin et al.

2018). The types of energy sources to power these processes, whether renewable or coal- or fossil-based, mainly impact the environmental footprint of SG.

For producing NG, the general challenges of mining mentioned in the chapters before apply as well. Especially, the challenges inherently related to waste disposal and post-closure surveillance of the environment after mining must be considered. Tailings and waste rock must be properly managed in appropriate mining waste facilities. In open-pit mining, damage to the surface and surrounding habitats must as well be considered and managed. These environmental impacts are associated with health and safety as well as social issues. In contrast, SG production depends on feedstock from coal and oil by-products, which bring their own challenges related to extraction. However, changing SG's carbon source is so far not feasible (Dolega et al. 2020).

For NG, the purification process also poses environmental and waste-related challenges. The chemical purification processes for NG often use inorganic acids, for which containment and disposal must be properly managed to prevent leaks that could lead to groundwater pollution or other environmental issues. For example, acids must be neutralised before they can be discarded. Thermal purification processes used also pose environmental hazards since they use high temperatures that require excessive amounts of energy (Dolega et al. 2020).

Overall, graphite mining/ production and processing are commonly associated with certain risks. These challenges – environmental destruction and pollution through mining and processing practices or accidents – are broadly manageable through regulations and certifications that ensure safe practices. The environmental impacts of NG production are directly connected to the regulatory powers of environmental rules for mining and processing while SG is especially linked to the types of and regulations on the energy sources that power production processes. For further information, see Dolega et al. (2020).

3.2 Cell Production

The **RE-SOURCING Project** will focus on the current production of lithium-ion battery cells (mostly with NMC and graphite as active materials). Challenges arise relating to:

- Environment: The production of cells is very energy intensive, which, depending on the source of energy used, is related to major emissions of GHG. Furthermore, the high susceptibility to errors leading to high scrap rates, especially at the beginning of production (2 % - 40 %). As battery cell production is very material intensive, it can lead to large waste streams that must be managed.
- Health & Safety: The LIB contains many toxic substances that must be managed to reduce impacts on the health of workers and the broader community. Faulty cells or cells damaged during production could pose a safety hazard, especially due to the possibility of thermal runaway.

The production of lithium-ion battery cells has increased exponentially over the last few years due to rising demand, especially to power electric vehicles. This trend is continuing, as many new cell production plants are starting their production in the next few months and even more have been announced to be built within the next several years. As battery cells are the key part of an electric vehicle, there is a strong connection between the original equipment manufacturers (OEMs) and the cell producers, since a battery is usually directly manufactured for the demands of a specific battery pack and car. Some OEMs produce battery cells themselves (e.g. Tesla or BYD) and others are planning to do so (e.g. Volkswagen).

In addition to responsible raw material procurement, battery cell production is connected to several additional challenges. To succinctly describe this complicated topic, the following sub-chapters present a technical overview about the typical LIB production today and then address the challenges of battery cell production.

3.2.1 Technical Overview

Commercial LIBs (lithium-ion batteries) used in passenger vehicles come in different battery cell formats: cylindric, prismatic or pouch cells. In all formats, the inside of the battery is filled with the cell stack, which combines both the electrodes (anode and cathode) on top of current collectors with the separator that is soaked in organic electrolyte (see Figure 14).

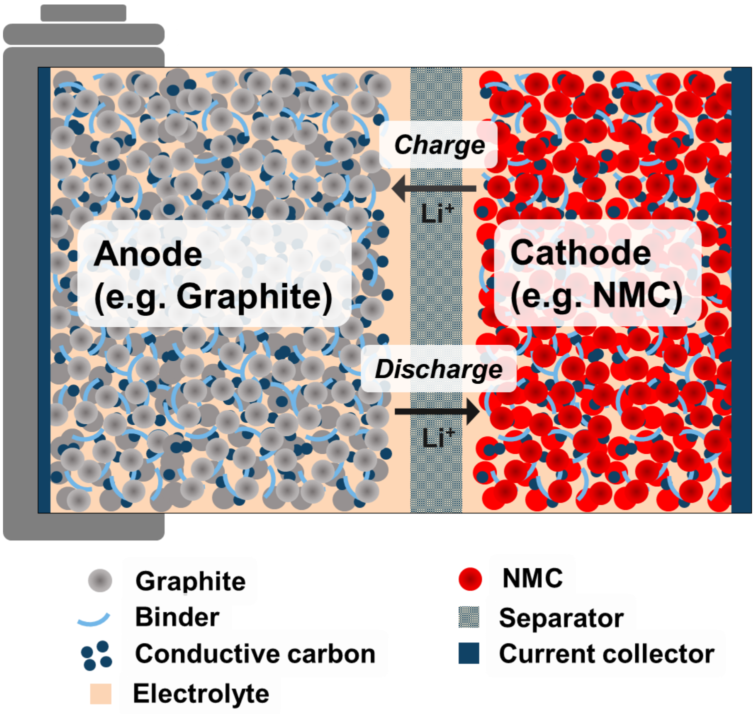


Figure 14: Schematic illustration of the electrode stack of an LIB; volume distribution true-to-scale (Redrawn from (Betz et al. 2020)).

The production of each of the different cell formats also starts in the same way, with production of the composite electrodes. Although electrodes may not seem particularly complicated, detailed engineering is required to produce electrodes that are suitable for their specific requirement profile, in this case for a traction battery for passenger vehicles. Both of the electrodes usually consist of an active material, a conductive additive to increase the electronic conductivity, and a polymeric binder to keep everything together on top of the current collector, which is coated with electrode paste on both sides (see Figure 14 and Figure 15).

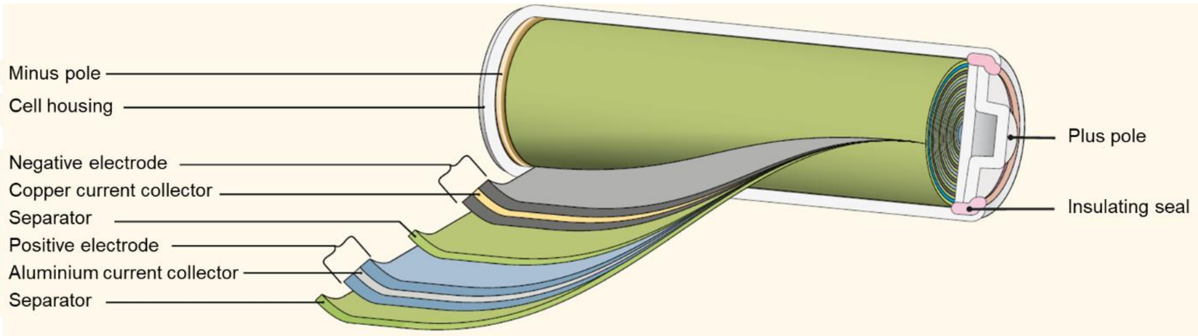


Figure 15: Cylindric cell with the electrode stack visible. Source: (Winter et al. 2017)

Apart from the chemistry of the active material itself and the parameters of the inactive materials, there are many electrode parameters that influence the performance of the resulting battery cell (e.g. particle size, structure and thickness of the electrode, ratio of the components). Every step of production of the electrode has an impact, and all parameters have to be chosen very carefully to fit the requirements and the other components, as they also have a strong impact on each other.

In the standard procedure for a solvent-based coating on top of the current collectors, as shown in Figure 16, the first process step involves dry mixing the active materials with the binder and the conductive additive to gain a homogeneous powder. After adding a process solvent, the resulting electrode paste, also called slurry, has to be homogenized, e.g. by an inline disperser (see step 1a in Figure 16).

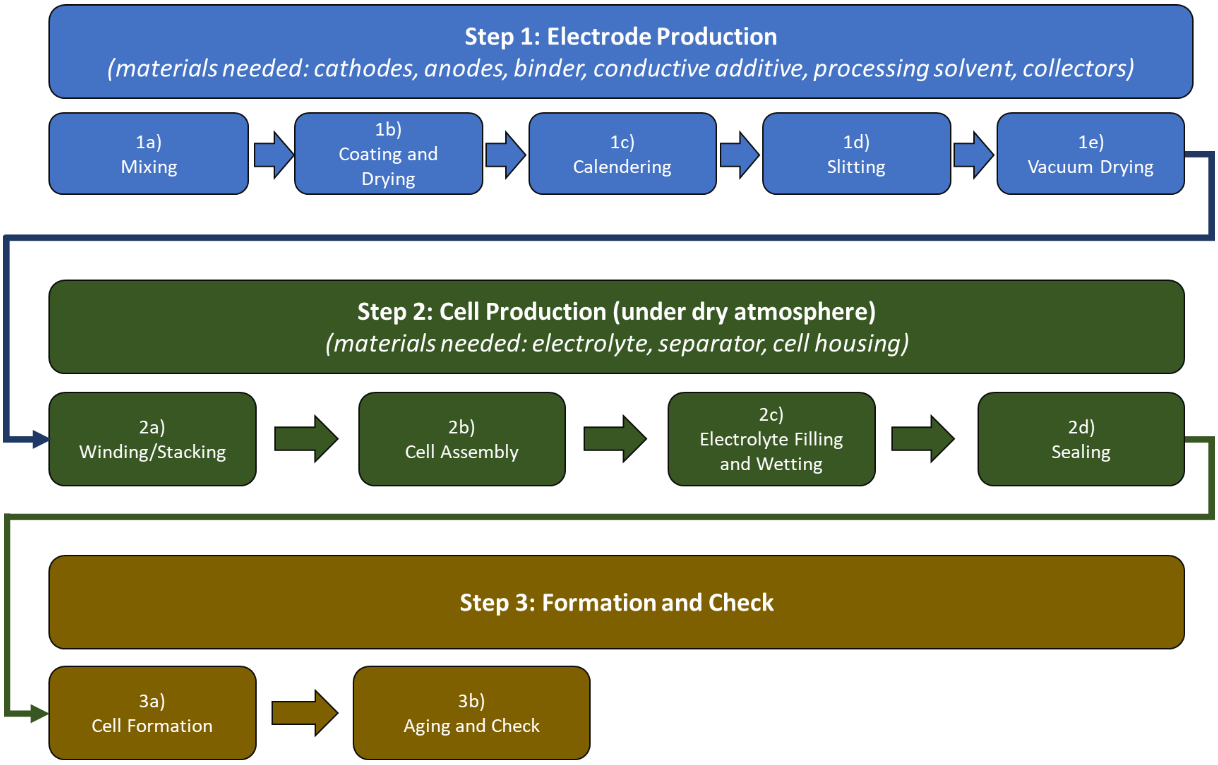


Figure 16: Overview cell production (Source: Oeko-Institut)

The properties of the paste, especially the viscosity, are again crucial for the resulting electrode. As can be seen in Figure 16, the coating on the current collectors from both sides happens in line with the drying process, usually using a convection dryer (1b). After densification by a calender (two rolls pressing the electrode sheet together, 1c), the electrodes are then sliced (1d), and cut and vacuum dried to remove all the remaining moisture (1e), as the cell chemistry with the electrolyte is very sensitive to moisture, especially when fully charged or when exposed to increased temperatures. Thereafter, the electrodes follow the production process for cell manufacturing. For cathodes, the current collector is generally aluminium, and the processing solvent is N-methyl-2-pyrrolidone (NMP). However, water-based processing is increasingly used. For anodes, water-based processing is standard, with the current collector made of copper.

Certain processes for cell production (step 2 in Figure 16) necessitate a dry atmosphere to keep the battery materials dry until the cells are properly sealed. For a cylindric cell, as shown in Figure 15, the electrodes are stacked with a polymeric separator in between and rolled up lengthwise, step 2a in Figure 16. They are next put in a metal casing and the current collectors are welded together (2b). The cell is then filled with electrolyte, usually under vacuum to improve the wetting process of the electrodes and the separator (2c).

After sealing, the formation of the cell (step 3 in Figure 16) has to take place to stabilize its long-term performance and check its functionality. Since a small part of the electrolyte decomposes during formation, gases are formed and a passivation layer builds up on top of the anode, the so-called solid electrolyte interphase (SEI). Pouch cells are usually degassed after the first formation cycle. To evaluate the functionality of the cell further, the LIBs are stored for a longer time, in part at elevated temperatures, and their status is checked regularly. If nothing changes, the LIBs are declared functional.

3.2.2 Challenges in Production

The production of LIBs is very price competitive. In addition, as already mentioned, the process is very material intensive. This has several consequences. First of all, economies of scale are crucial. The larger the production plant and the input and output, the lower the price per battery can be, which means that only large factories are competitive.

In addition, production itself is very susceptible to errors, which leads to high scrap rates. Especially at the beginning of a plant's production directly after construction, scrap rates can be in the higher double digits. Combined with high material intensity, this leads to a lot of waste that needs to be taken care of. Waste recycling needs to be established from the start and ideally in close proximity to the production, and logistics is key to manage the high input and output. Waste recycling allows a battery cell producer to regain the active materials from production scrap if the process is conducted well (see chapter 3.3.1). Production is dependent on material flows from all over the world and, similar to vehicle production, all parts must be available all the time or production will have to stop. The dependence on supplies from mining also raises the issue of due diligence, as cell manufacturers must monitor their extensive supply chain for the origin of their resources and the social and environmental conditions under which they were extracted.

Another challenge is the danger posed by LIBs. Defective cells or cells damaged during production could pose a safety risk, especially due to the possibility of thermal runaway. Safety precautions must be taken, especially when forming and testing the cells as they are charged and discharged. LIBs are assembled in a discharged state and charging the battery greatly increases the potential risk. Solvents (for manufacturing and as part of the electrolyte) also pose safety hazards. Many other substances used for production are as well toxic, such as the cathode active material if it contains cobalt or nickel. Sometimes, additional coatings of partly toxic doping elements like chromium (Cr) are also involved.

But even if the material itself is not dangerous, such as graphite, inhaling the powder form of the material can also be dangerous for workers who come into contact with it. For further information, see Dolega et al. (2020).

The electrolyte usually contains lithium hexafluorophosphate ($LiPF_6$) as the conducting lithium salt. This substance is not only toxic, but in combination with moisture and elevated temperatures it decomposes to hydrofluoric acid (HF), a very dangerous chemical. In addition, the electrolyte and its salt also partially decompose into other highly toxic products during the formation of the cells. In production, toxic process solvents such as N-methyl-2-pyrrolidone (NMP) are often used to coat the NMC cathode. NMP must be recovered during the drying phase, as its release into the environment has serious consequences. For LFP as a cathode material and the graphite anode, water is the standard processing solvent.

However, the main challenges for battery cell production are the very energy intensive processes, which, depending on the used energy mix, lead to GHG emissions and result in large carbon footprints (Larcher & Tarascon 2015). Several production processes are responsible for high energy consumption. First of all, certain aspects of battery production need to happen in a dry atmosphere, as the chemicals used are moisture sensitive (see Figure 16). These processes are usually performed in a dry room, where the air contains nearly no water. To dry the air as required, it has to be cooled to below -65°C, the water has to be removed and the air has to be heated up again. This process requires huge amounts of energy, especially if the room is large enough to contain several workspaces. The drying of electrodes after coating by convection drying as well as the formation and aging of cells (incl. temperature control, charging/discharging) are also energy intensive. Several improvements, like recuperation during discharge of the cells to save energy, are already state-of-the-art.

These and further environmental challenges are depicted in Figure 17.

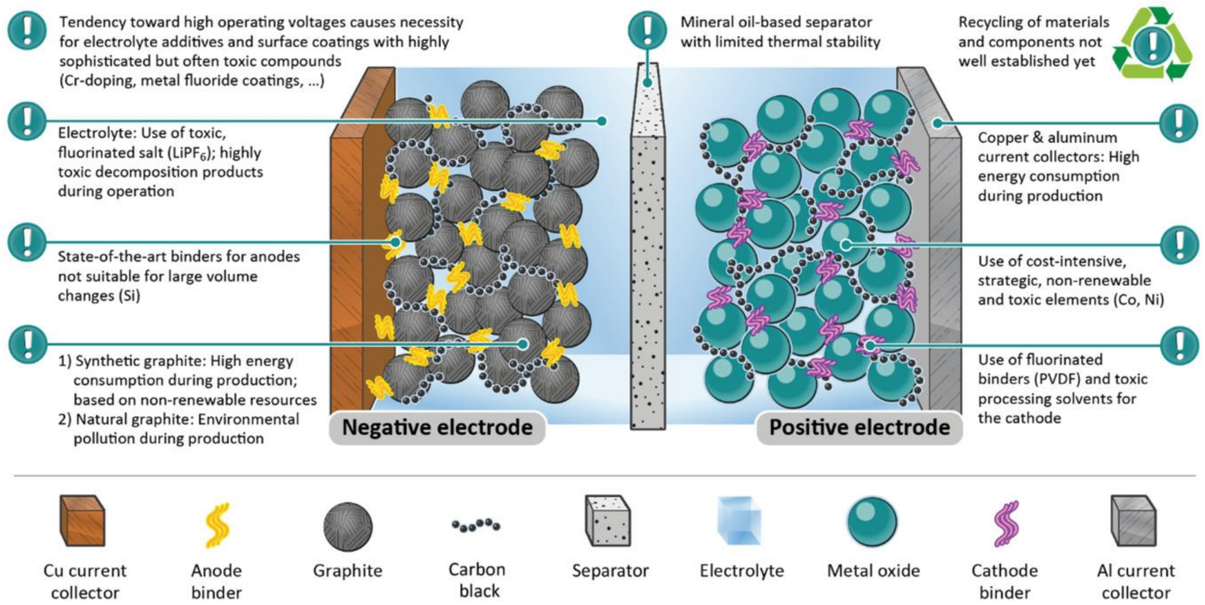


Figure 17: Environmental challenges of current materials and components in state-of-the-art LIB cells (Dühnen et al. 2020).

3.3 Recycling

The **RE-SOURCING Project** will focus on **lithium-ion battery recycling**, incl. collection, transport and logistics. Challenges arise relating to:

Health & Safety: Waste batteries can pose a safety risk. Therefore, it is crucial to treat the waste stream with the necessary safety standards. Recycling LIBs as the only option for a circular economy is not yet common practice in all parts of the world, as it is difficult and often costs more than the resulting recycled material brings in when sold. However, recycling of batteries is becoming more common.

Environmental Impact: Recycling LIBs can be energy intensive and, if not done appropriately, results in significant emissions of pollutants to air and water. Depending on the energy source, greenhouse gases are also emitted, but the savings from the recovered materials are usually greater.

This chapter addresses LIB recycling. First, the technological status of LIB recycling in the Europe and the rest of the world is evaluated. Then, the challenges related to collection, transport and logistics as well as the recycling process itself are analysed.

3.3.1 Technological Status of Lithium-Ion Battery Recycling

Lithium-ion batteries (LIBs) for electric vehicles (EVs) have different cell compositions. When the first EVs were produced, mixtures of NMC and LMO[8] were often used in the traction batteries. Today, NMC battery cells dominate the market for electric cars, followed by NCA[9] cells (Oeko-Institut 2019), although there is a trend for LFP cells for smaller EVs, as mentioned earlier. In contrast to portable batteries, LIBs for electric vehicles consist to a large extent of other add-on components (up to about 40 % by weight), such as battery casings, cables, battery management systems, various screws, plastic parts, etc.

LIBs for disposal in passenger cars have to be first removed properly. Due to the batteries' high voltage, only specially trained electrotechnical personnel should remove traction batteries from vehicles. Upon removal, the LIBs can be transported as dangerous goods to dismantling plants. Depending on the process, LIBs are discharged if necessary and components such as casings (steel/plastic/aluminium), cables (copper), and battery management systems (PCB scrap) are removed by hand by specially trained personnel. These components are fed into existing, conventional recycling plants (steel, copper, aluminium recycling, etc.). To protect workers in the dismantling plants from possible pollutant emissions in the event of an accident (especially hydrofluoric acid and solvents), the workplaces must be well ventilated. If dismantling and recycling of the battery cells do not take place at the same location, the cell modules are separated and securely packaged (insulated by sand or vermiculite for safety reasons) to be transported to the recycling plant (Buchert et al. 2020). Similar to the recycling routes for portable LIBs, in Figure 18, pyrometallurgical, mechanical or pyrolytic

[8] lithium manganese oxide, $LiMn_2O_4$ or similar
[9] lithium nickel cobalt aluminium oxide, $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ or similar

processes are usually used to further treat the LIB cell modules from electric vehicles in the next recycling step, depending on the process or company.

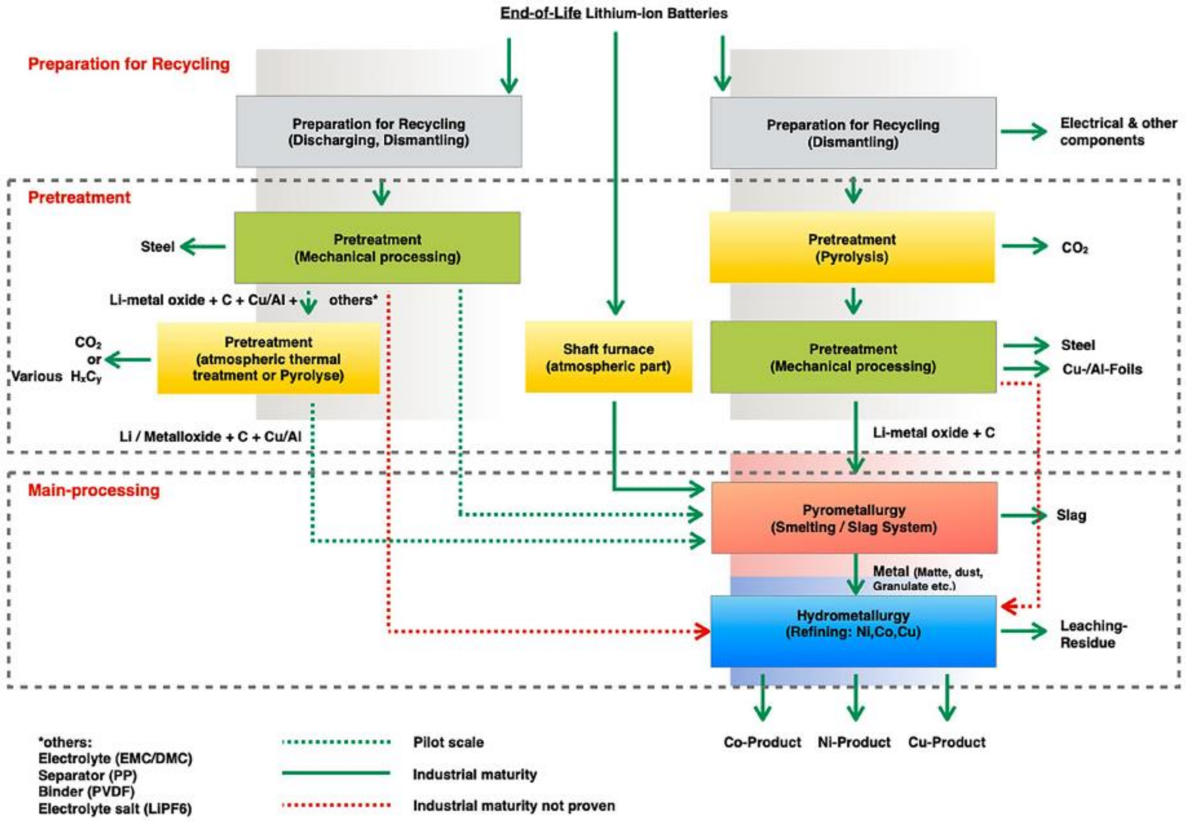


Figure 18: Overview of recycling routes of LIBs (Source: Sojka et al. 2020)

The processes for recycling LIB battery modules differ substantially in their first steps; in addition to mechanical separation, there are processes that use pyrometallurgical pre-treatment steps with subsequent mechanical separation or pyrolysis in a shaft furnace (see Figure 18).

Further processing of the recovered materials then takes place along different hydrometallurgical or pyrometallurgical paths (with subsequent hydrometallurgy), depending on the process. Today, the main target materials of the recycling process are copper, nickel and cobalt (Sojka et al. 2020). Lithium is currently the focus of only a few recycling processes, although it is likely to become much more important in the future due to increasing volumes from waste batteries. Furthermore, the proposal for the new EU battery regulations includes, apart from cobalt, recycling targets for copper and nickel (90 % in 2026, 95 % in 2030) as well as recycling targets for lithium (35 % in 2026, 70 % in 2030) (European Commission 2020b). It should be explicitly noted that the depiction of the recycling routes in Figure 18 represents an ideally typical picture overall. On the one hand, process steps such as the hydrometallurgical treatment of the "black mass" or the recovery of lithium are still hardly realised in the various processes, or the transparency of the corresponding recycling companies with regard to these processes is still in great need of improvement. On the other hand, optimisation is still necessary for almost all process steps in all routes and is therefore planned for the next few years.

In the pyrometallurgical route, the LIB modules are melted directly in a shaft furnace at high temperature. For example, at Umicore's battery recycling plant in Hoboken, Belgium, an alloy is obtained consisting mainly of the target metals copper, cobalt and nickel. In this high-temperature process, graphite, organic solvents (from the electrolyte) and plastic components of the batteries as well as the residual electrical energy of the battery cells are used as energy sources and the resulting carbon dioxide is emitted via the waste gas stream. Fluorine is integrated into the fly ash via the waste gas purification system and disposed of as hazardous waste.

To avoid hazardous emissions such as dioxins and furans, the waste gas purification system is equipped with a plasma burner as a high-temperature afterburner. During the smelting process in the shaft furnace, the lithium contained in the batteries is completely incorporated into a slag, which is separated as a by-product. Until 2017, this slag was used as construction aggregate. According to Umicore, since 2017, lithium carbonate or lithium hydroxide has been recovered from this slag by third parties so that it is also available again for incorporation into the battery cycle. More information and details about this process are not yet known (Buchert 2020). The alloy obtained is hydrometallurgically separated and purified into copper, cobalt sulphate and nickel sulphate at another Umicore plant in Belgium. The cobalt and nickel sulphate are reused to produce cathode material for LIBs.

When mechanical treatment is the first step of the battery pre-treatment process (see Figure 18), for example, the LIB modules are shredded in an inert gas atmosphere, and part of the electrolyte (low boiling point) is recovered after vacuum evaporation. There are R&D activities to separate these solvent mixtures and to return the solvents to the economic cycle.

When pyrolytic treatment is the first step of the battery pre-treatment process (see Figure 18), the LIBs are first thermally treated and then shredded. In these processes, the electrolytes (organic compounds) are pyrolysed (waste gas cleaning required) and the fluorine-containing binder for the cathode and anode material is destroyed. Binder destruction combines the advantages of better separation in the subsequent mechanical stage with early separation of fluorine compounds already in the pyrolysis step. The energy content of the LIB modules and their organic electrolytes contribute to a favourable energy balance for this step. Subsequently, after both pre-treatment routes (mechanical or pyrolytic pre-treatment), steel, aluminium and copper components are separated mechanically and sent for conventional recycling.

Purely mechanical routes have, however, the disadvantage that the binder of the battery cells makes it much more difficult to separate the active materials from the copper or aluminium foils. The main product is the so-called "black mass", which mainly consists of electrode material (graphite, lithium, cobalt, nickel and manganese oxide). This can be further processed either in pyro-metallurgical (with subsequent hydro-metallurgical cleaning and separation steps) or hydro-metallurgical plants. The target materials are copper, nickel and cobalt compounds. The recovery of lithium has so far been realised in very few processes or is at the R&D stage. Furthermore, in the case of the routes with mechanical or pyrolytic pre-treatment, there are also R&D activities for the recovery of graphite from the LIBs.

It is difficult to relate the recycling efficiencies directly to recycled content in new battery cells, as the market is very dynamic and growing strongly. In 2011, the fraction of secondary (scrap) metal in the total metal input to metal production of nickel and cobalt was between 29 % and 41 %, for copper between 20 % and 37 % and for lithium below 1 % (Graedel et al. 2011). However, especially the values of cobalt and nickel are impacted by the recycling of stainless steel, catalysts and super alloys, which traditionally have high recycling rates. Although the recycling capacities have been growing over the last few years, the demand for these metals has risen strongly as well. Therefore, it is difficult to assume certain recycled content in lithium-ion batteries.

Waste management challenges from relevant waste streams become evident along every step of the battery manufacturing process. In particular, a small portion of batteries often have to be discarded in the last processing steps. When this happens, these mostly complete yet defective battery cells cannot simply be repaired; they must be recycled in the same processes as used end-of-life batteries to prevent safety hazards. In contrast, waste materials from earlier production steps still may have the possibility to be kept separate from each other to simplify their recycling process, for example by separating anode and cathode waste materials. While only comparatively small amounts of such pre-separated waste are generated during battery cell production, setting up direct recycling processes for such waste could prevent further contamination and extra waste generation.

3.3.2 Challenges of LIB Recycling

Battery recycling generally faces several legislative, environmental, social, and technical challenges. At the highest level of regulation, the current Battery Directive of the EU lacks strong collection targets for LIBs that have reached their end-of-life (EoL) – except portable batteries with the collection target of 45 %). Furthermore, a recycling efficiency target of 50 % by weight applies to LIBs in the EU. This very unspecific target has been highly controversial among experts and market participants for some time. In the new proposal for a battery regulation from the EC, these values are increased (see chapter 4.2.5 or more details).

Hazardous battery content

Among the greatest challenges in the various battery cell recycling and transport processes is the control of thermal runaway (TR) and the high fire load of an LIB. According to Weyhe and Buchert (2019), the TR phenomenon makes LIBs often associated with fire incidents. Fires are caused by heating or mechanical damage to a cell. Internal pressure then builds up, bursting the battery cell and causing subsequent spontaneous combustion of the cell, electrolytes (organic solvents) and plastics. Heating of the LIB cell can be caused by an external short circuit, by an internal short circuit, by strong heating from the outside or by external damage. The TR of a lithium-ion cell can lead to particularly rapid and large fire events if there are many lithium-ion cells in a dense room. The reason is that the energy of one charged cell is sufficient to heat six other cells to TR temperature (150 - 250 °C). This leads to a fatal domino effect. In addition to the heat of combustion, there is also a high potential hazard due to considerable emission of soot, hydrofluoric acid (HF) and carcinogenic hydrocarbons. This fire hazard impacts and augments all challenges associated with producing, handling and recycling LIBs.

In particular, LIBs' fire hazards mean that all areas of the recycling industry where LIBs are collected, transported, stored and treated must be organised and technically equipped in such a way that the TR of a cell can be detected as quickly as possible and countermeasures can be initiated or the extent of damage can be kept as low as possible. To improve safety, some recyclers pre-treat battery cells with a saltwater bath. This reduces the immediate dangers from the batteries, although it often does not fully deactivate the cell, but generates more waste and the associated challenges. Other recyclers use the deactivation option of heat treatment, which requires special ovens and filtration of gas emissions. Generally, the measures implemented to improve logistics security make battery cell transport expensive. This is even more true for large and damaged but still active batteries.

Furthermore, Lithium-ion battery cells contain hazardous substances, such as the electrolyte and other toxic metals (see chapter 3.2.2), that must be handled and disposed of properly. In particular, LIB conducting salts easily decompose to hydrofluoric acid, a highly toxic and corrosive substance that requires special care. This is especially problematic if workers are not protected properly against such risks and if these hazardous substances are not contained properly and have a negative impact on the surrounding environment.

Storage and transport risks

Battery cell storage and transport also faces the challenge of securing sufficient space, since stacking cells is only deemed safe in certain instances. Overall, the growth in demand for battery cells further increases the need for safe infrastructure to store and transport the expected higher waste stream of spent batteries.

Some of the recyclers complain about too much risk accepted in (waste) battery cell transport. This stems from safety concerns not having been the driving force to develop the current logistics infrastructure and is partly augmented by missing reverse logistics, for example in tracking and data management. Overcoming these logistics risks is critical to being prepared to handle the high transport volumes of battery cells that are expected.

Lack of information

Battery recyclers indicate challenges with having sufficient information about a battery cell's condition. More specific information about a battery's status could help recyclers know which modules have higher fire hazards because of, for example, degraded chemical or electrical conditions. Also, information about quality of recovered materials are important to enhance cooperation between all the actors of the value-chain and recirculate materials (e.g. link between recyclers and manufacturers).

Design

Common designs for LIBs do not always provide for the possibility to disassemble cells or modules from packs, which would facilitate recycling. The trend even goes in the opposite direction, leaving out the module and going directly from cell to pack, combining everything by glue to save weight, volume and material, but making disassembly or repair nearly impossible.

Recyclers also recommend ensuring that the battery housing can be recycled separately from the battery cell. To reduce waste, waste battery components or defective elements resulting from production should be kept separately for more efficient, sometimes even direct recycling.

Environment

There is no environmentally sound alternative to recycling battery cells, as it is important to reduce the risk of EoL battery cells and recover at least some of the resources invested in them. Nevertheless, recycling itself can also lead to environmental hazards. First of all, most recycling processes lead to direct and indirect greenhouse gas and other emissions. The direct emissions come from the combustion of organic parts of the battery cell during heat treatment. As the EoL battery also contains several fluorine-containing organic compounds, the emissions in the air must be well filtered. Indirect emissions come from the energy used to heat and recover the materials, depending on the energy source used. With a higher share of renewable energy, the latter can be reduced. Hazardous substances are another problem if they are not properly handled and contained. This is especially the case if the EoL batteries are processed with water, which must be treated before being released into the environment or should be completely closed loop.

Economy

Although most LIBs used for electric mobility contain valuable materials like copper, Co or Ni, it is difficult to gain money from the recycling of EoL batteries. The most important factor is the cost intensive logistics, as it is related to a lot of risks. Furthermore, economies of scale are also important for the recycling itself. At the moment, in Europe, the stream of waste batteries is still small. As soon as the stream will increase, some of the costs will decrease. However, at the same time, also the battery chemistries itself change constantly. While Co still contains some value and can lead to a financial benefit, the other metals are not valuable enough to sustain the recycling of EoL batteries yet. With the battery chemistry changing to cathodes with less cobalt and sometimes even to LFP as cathode material, which holds no material value at all, this has also an impact on the recycling market.

Therefore, it is necessary to have mandatory public policies concerning recycling. In the EU, 50 % by weight of a collected battery has to be recycled. The new proposal by the EC wants to increase this share as mentioned earlier, including specific recycling targets for Li, Ni, Co and Cu (European Commission 2020b). The price for recycling should be paid by the distributor, which, in case of the mobility sector, is the OEM. This is very important, as otherwise, there is the danger that EoL batteries will not be recycled at all. In other countries, there are different regulations concerning EoL batteries. Some do not even have any regulations, which could lead to massive problems in the future.

To sum up, different process routes for recycling LIBs are pursued by the various recycling companies in the EU and worldwide. Recycling of the two valuable metals nickel and cobalt from LIBs has been the main focus of recycling activities up to now, along with the recovery of copper. Since LIBs at their EoL have so far been only moderately returned to the recycling industry, recycling plant sizes for LIBs in the EU have only needed to process a few thousand tonnes of batteries. In the next ten to 15 years, the return of LIBs from the electromobility sector to the recycling sector is expected to surge in the EU. This will increase the need for both larger recycling facilities and optimised recycling processes. The recovery of lithium and also graphite from end-of-life LIBs will therefore become significantly more important in coming years. Recycling itself, although necessary, may also present social and environmental impacts such as chemical hazards, intense energy use and GHG emissions.

4 Standards and Initiatives

The mobility sector applies many standards and initiatives along its entire value chain. As part of the project's focus on the traction battery for electric vehicles, the following chapters review specific standards and initiatives that address the raw materials lithium, cobalt, nickel and graphite. There are many possibilities to cluster the initiatives, for example based on whether they are mandatory or voluntary, their geographic focus or relevance. In this case, the initiatives have been clustered based on the sector they address, in line with the selected value chain steps. Furthermore, the standards and initiatives are clustered with different colours:

- ***Mandatory regulations*** *(bold red): Regulation, European Directives and the Basel Convention*
- *Mandatory standards (orange): IFC Guidelines, LME, EITI, ILO, TSM (for Canadian mining companies operating in Canada)*
- *Voluntary standards (green): IRMA, Global Tailings Review, CTC, WEEE Standard, ISO, GRI*
- *Guiding principles (blue): OECD Due Diligence Guidelines, OECD Multinational Enterprises, China Responsible Mineral Supply Chain Die Diligence Management guide, Cobalt Industry Responsible Assessment Framework (CIRAF), UN Human Right Principles*
- *Initiatives (black): ICMM, ARM, European Raw Materials Alliance (ERMA), Responsible Minerals Initiative, Fair Cobalt Alliance, Responsible Cobalt Initiative, World Bank Climate-Smart Mining Initiative, Drive Sustainability, European Battery Alliance (EBA), Global Battery Alliance (GBA), European Green Vehicles Initiative (EGVI)*
- *Sustainable Development Goals (SGDs) in purple*

The broad aim is to provide an overview of the vast number of different guidelines, certification schemes and standards, both for the value chain steps and on a general level.

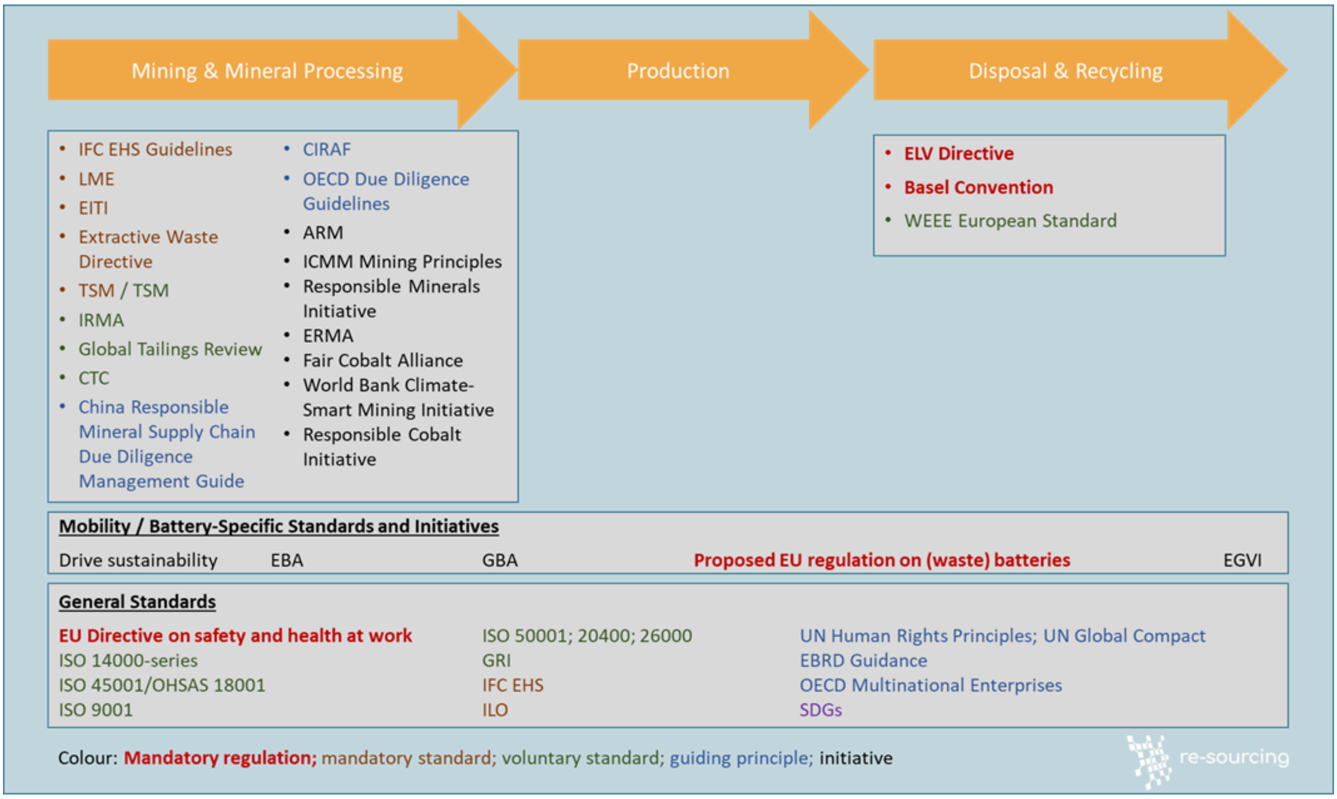


Figure 19: Overview of selected standards and initiatives (Source: Oeko-Institut)

The increasingly common use of the term 'responsible sourcing' can be noted in communications from international institutions, national governments, corporations and civil society. In step with this, voluntary initiatives encourage responsible and sustainable production practices along the entire supply chain. Various and sometimes overlapping standards and initiatives also apply to the mining sector, though no international standard has been set. This absence of an international framework poses challenges to defining 'responsible sourcing' from producer and user perspectives. With responsible sourcing seen as one tool for overcoming resource depletion, human rights violations and climate change, the mobility sector requires a harmonisation of standards and initiatives to facilitate positive change.

This chapter focuses on the standards and initiatives that apply to lithium-ion batteries (LIBs) along their value chain (see chapter 4.1 and 4.2) and in particular to raw material mining (see chapter 4.3) and LIB recycling (see chapter 4.4) The lists of standards presented here are by no means complete but instead address the most widely used or effectively rated standards and initiatives.

4.1 General

The following initiatives and standards do not only refer to the mobility sector but are also relevant for other sectors. They are not limited to individual steps of the value chain. Therefore, these standards and initiatives are already included and explained in the renewable energy sector evaluation. (See the State of Play and Roadmap concepts: Renewable Energy Sector (RE-SOURCING 2021).

4.1.1 Environmental Health and Safety (EHS) Standards in the EU

The EU has very broad legislation addressing environmental safety and health, which is divided into EU Directives, guidelines, standards and additional national legislation (e.g. the Council Directive 92/104/EEC of 3 December 1992 on the minimum requirements for improving the safety and health protection of workers in surface and underground mineral-extracting industries.) These standards are managed under the EU-OSHA, the European Union information agency for occupational safety and health. For more information, see the EU-OSHA website[10] on safety and health legislation.

4.1.2 European Bank for Reconstruction and Development

The European Bank for Reconstruction and Development (EBRD) maintains policies addressing, among others, environmental and social governance, transition to a green economy, and various industries. Part of its sub-sectoral environmental and social guidelines, one policy addresses mining, the extractive industries and mineral processing. This document mainly seeks to help financial officers in their decision-making, but it as well offers governments a guide for developing policies as well as aids companies in good corporate practices.

The guidelines proposed by the EBRD are grouped into six categories: 1) competitive, addressing local sourcing, new technologies and operational efficiency; 2) well-governed, including health and safety management, Extractive Industry Transparency Initiative (EITI) principles and specific corporate governance action plans; 3) inclusive, addressing local recruitment and training programmes as well as workforce diversification and development locally; 4) green, looking at environmental management and the impacts from successful management, energy efficiency and EHS regulations, among others; 5) resilient, including financial instruments to support development and mitigate market shocks; and 6) integrated, addressing among others product portfolio diversification for access to new markets and mining structure use by local communities and businesses. As well, the EBRD's *Environmental and Social Policy* lays out precise performance requirements for such issues as labour and working conditions, environmental and social risks, and biodiversity conservation (EBRD 2017).

4.1.3 Global Reporting Initiative

The Global Reporting Initiative (GRI) provides a voluntary standard for companies from various sectors along the entire supply chain to achieve sustainable reporting and increase transparency. The standard aims to help corporations comprehend and communicate their influence on sustainability issues, including governance, human rights, social well-being and climate change. This initiative holds as a tenet that maintaining an informed public through transparency can influence corporate decisions and promote positive change (GRI 2020; BGR 2017).

4.1.4 International Finance Corporation, World Bank Group

The World Bank Group requires its clients to employ relevant measures that are defined under its *Environmental, Health, and Safety Guidelines*, or 'EHS Guidelines'. This collection of technical reference documents that the International Finance Corporation (IFC) developed can be applied to all industry sectors in combination with the appropriate *Industry Sector Guidelines* that the IFC has defined (see ch. 4.3.10 for more details). The EHS Guidelines group recommendations into four categories: 1) Environmental, addressing energy, water and waste issues; 2) Occupational Health and Safety, with guidelines for facilities to mitigate various hazards; 3) Community Health and Safety,

[10] https://osha.europa.eu/en/safety-and-health-legislation (18.03.2021)

addressing clean water access, transport and infrastructure and public health; and 4) Construction and Decommissioning, defining concerns relating to the first three categories (IFC 2020).

4.1.5 International Labour Organisation (ILO) Conventions and Recommendations

The International Labour Organisation (ILO), an agency under the United Nations, broadly seeks to provide a system of international labour standards that support social justice. The standards, policies and programmes that it develops should promote safe and decent work. Labour standards are defined under legally binding 'conventions', eight of which are seen as fundamental, as well as certain associated 'protocols' and non-binding 'recommendations'.

The *Declaration on Fundamental Principles and Rights at Work* outlines four basic policies: a) Workers' freedom of association and collective bargaining; b) termination of forced and compulsory labour; c) end of child labour; and d) the elimination of unfair discrimination. The policies are complemented by the ILO chemicals convention, which includes hazardous substances and health and safety. These international standards, applicable to all industries and service sectors, have been adopted by the vast majority of countries worldwide in the effort to reduce inequalities and inhuman working conditions. Countries must themselves apply the standards on a national level.

4.1.6 ISO Standards

The International Standards Organisation (ISO) develops standards in diverse areas that are internationally recognised. Among these areas are standards addressing quality management, environmental management, health and safety or energy management – many of which are relevant for the supply chain in the mobility sector.

Environmental management standards and guidelines are listed in the **ISO 14000 series**, which certifies companies according to ISO 14001:2015. Documents within the ISO series support implementation of the standard, with the goal to improve an organisation's environmental performance. Under this certification, companies must have an environmental management system that can identify, manage, monitor and prevent environmental issues. A third-party auditor can grant accreditation, which requires periodic updating. As part of the series, companies are encouraged to more efficiently use resources, reduce waste and create trust with their stakeholders. A standard particularly important to the LIB supply chain, ISO 14064 provides tools for addressing greenhouse gas (GHG) emissions (ISO 2015b, 2015a, 2018d).

The **ISO 45001** standard, based on OHSAS 18001 from the International Labour Organisation, provides a framework for occupational health and safety management systems. It seeks to reduce work-related injuries and diseases, which is complemented by minimizing hazards and risks and promoting physical and mental health. The certification emphasises continual improvement and encourages corporate leaders to be accountable for health and safety standards in their organisations (ISO 2018b).

Corporate energy management is covered under **ISO 50001**. The standard offers guidelines to systematically improve energy performance through energy efficiency, security, use and reduced consumption, which should thereby reduce greenhouse gas emissions (ISO 2018c).

ISO 26000 offers guidelines on social responsibility to organisations. It seeks to help organisations in developing sustainably by providing background, principles, practices and the core issues that define social responsibility. This includes methods for how to include social responsibility in corporate policies and practices and in stakeholder engagement, in part by encouraging transparency in commitments and performance (ISO 2018a).

Responsible sourcing is addressed under the guidance provided by **ISO 20400**. Titled *Sustainable procurement*, the guidelines provide organisations with a framework for procurement processes and for implementing sustainability considerations. The guidance encourages organisations to analyse suppliers based on the working conditions and product sustainability they offer, providing guidelines for, among other issues, transparency, accountability and respect of human rights (ISO 2017).

Other relevant ISO standards include the **ISO 9001** for Quality Management Systems.

A new ISO standard is in development, specifically designed for the standardization of '**lithium** mining, concentration, extraction, separation and conversion to useful lithium compounds/materials (including oxides, salts, metals, master alloys, lithium-ion battery materials, etc.)' (ISO 2021). The work programme includes terminology, uniform testing and analysis methods to improve the overall quality of lithium products and the technical delivery conditions to overcome transport difficulties (ISO 2021).

4.1.7 OECD Guidelines for Multinational Enterprises & Due Diligence Guidance for Responsible Mineral Supply Chains

The Organisation for Economic Co-operation and Development (OECD) maintains the framework *Guidelines for Multinational Enterprises*, which complements its *Due Diligence Guidance for Responsible Mineral Supply Chains*. These two guidelines spell out governmental recommendations for responsible business conduct, expectations, and legislation for specific countries. As part of its definition of 'responsible business conduct', the guideline indicates the importance of identifying and managing risks in a company's supply chain and operations, contributing to economic, social, and environmental development in a host country, and contributing overall to the sustainable development goals. The OECD's *Due Diligence Guidance* further provides practical support to implement the *Guidelines*, which is further elaborated in chapter 4.3.13 (OECD 2020c, 2020d).

4.1.8 Sustainable Development Goals (SDG)

As the United Nations defines its 17 goals, 'the Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all.' These 17 goals, which all UN member states agreed to achieve by year 2030, address a variety of issues, among them human rights, responsible consumption and production practices, poverty and global warming (United Nations Sustainable Development 2020).

4.1.9 UN Human Rights Principles

Forming the basis of many aforementioned standards, the human rights principles laid out by the United Nations (UN) in the *UN Guiding Principles on Business & Human Rights* provide guidelines on 'the duties of countries and enterprises in respecting and protecting the human rights' (United Nations Human Rights 2011).

4.2 Mobility / Battery-Specific Standards and Initiatives

The initiatives and standards described here focus on the whole value and supply chain for batteries.

4.2.1 Drive Sustainability

Facilitated by CSR Europe, the automobile sector has set up the Drive Sustainability partnership to improve the sustainability of the automotive supply chain. The partnership has drawn up the Auto*motive Industry Guiding Principles to Enhance Sustainability Performance in the Supply Chain* that is accompanied by *The Global Automotive Sustainability Practical Guidance*. These Principles and

Guidance documents define and provide examples for efforts toward ensuring 'fundamental principles of social and environmental responsibility' in the areas 'Business ethics', 'Environment' and 'Human rights and working conditions' (Drive Sustainability 2020). Automobile companies are reminded of their obligation to comply to local laws and international standards at a minimum. The partnership therefore promotes 'standardization and harmonization of supply chain approaches to achieve long term impact, while also maintaining independent supply chain management'. They consequently seek to integrate sustainability into the broader procurement process (Drive Sustainability 2021).

4.2.2 European Battery Alliance

In 2017, the European Commission started the European Battery Alliance (EBA) with its focus on making 'Europe a global leader in sustainable battery production and use' (European Commission 2021). The Alliance brings together stakeholders from governmental authorities and industry research institutes to promote a thriving, but also sustainable, battery value chain in Europe. While several multi-billion-Euro programmes have been set up for research and development of batteries as part of the EBA and beyond (complemented by Batteries Europe and Battery 2030+, see Figure 20), the focus of the EBA is not the sustainability of batteries or specific standards for the battery value chain. Nonetheless, several of their objectives are linked to battery standards and sustainability (increased mining and battery production in Europe, recycling of batteries and others), as EU industry has stronger regulations compared to other countries (EBA 2021). For more information, see the European Commission's website[11] on the European Battery Alliance.

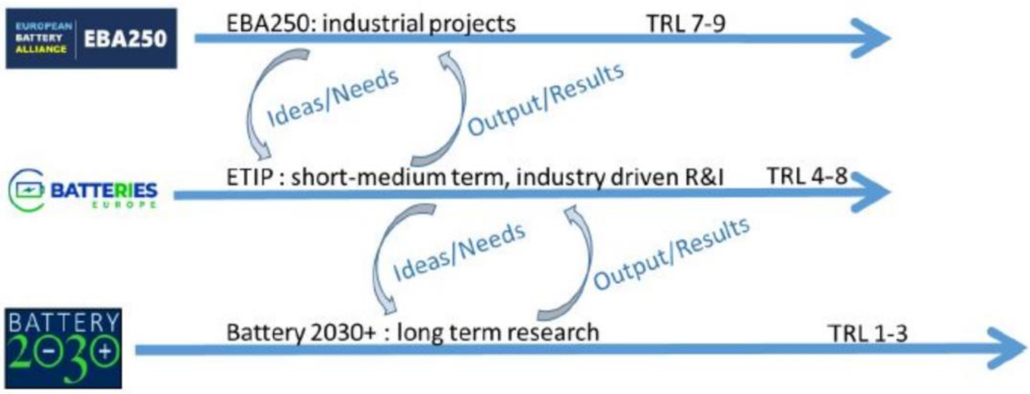


Figure 20: Overview of the European Battery Alliance, Batteries Europe and Battery2030+ (Di Persio et al. 2020)

4.2.3 European Green Vehicles Initiative (EGVI)

The European Green Vehicles Initiative (EGVI) combines several key stakeholders of the mobility sector to favour 'green vehicles'. They started the initiative *Towards zero emission road transport* (2Zero), a partnership to achieve carbon-neutrality in road transport by 2050 (EGVI 2020).

4.2.4 Global Battery Alliance

Global Battery Alliance (GBA) is a project by the World Economic Forum. As a global collaboration platform, it will catalyse and accelerate action towards a socially responsible, environmentally sustainable and innovative battery value chain to power the Fourth Industrial Revolution towards

[11] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en (15.03.2021)

automation of industrial practices and manufacturing through the implementation of modern 'smart' technologies.

GBA has 10 *Principles for a sustainable battery value chain*, which as of 23 January 2020 had been adopted by 42 organisations (WEF 2020a). The ten Principles are:

1. Maximizing the productivity of batteries in their first life
2. Enabling a productive and safe second life use
3. Ensuring the circular recovery of battery materials
4. Disclosing and progressively decreasing greenhouse gas emissions
5. Prioritizing energy efficiency measures and substantially increase the use of renewable energy as a source of power and heat when available
6. Fostering battery-enabled renewable energy integration and access with a focus on developing countries
7. Supporting high quality job creation and skills development
8. Immediately and urgently eliminating child and forced labour, strengthening communities and respecting the human rights of those employed by the value chain
9. Fostering protection of public health and the environment, minimizing and remediating the impact from pollution in the value chain
10. Supporting responsible trade and anti-corruption practices, local value creation and economic diversification (WEF 2020a)

One of the GBA's flagships is the 'Battery Passport', which they state should 'offer a digital representation of a battery, conveying information about all applicable environmental, social, governance and lifecycle requirements based on a comprehensive definition of a "sustainable" battery'. It is planned to be fully operational at the end of 2022 (WEF 2021).

Three further 'Impact programmes' have been developed: (WEF 2021)

- *Establishing a responsible and sustainable cobalt supply chain*: special focus on child labour
- *Low-Carbon Economy Programme*: focus on distribution of batteries to safe emissions
- *Circular Economy Programme*: focus on lowering barriers for shipment of spent batteries to increase recycling

For further information, see the World Economic Forum's website[12] on the Global Battery Alliance.

4.2.5 Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries

In December 2020, the European Commission published a proposal for new battery regulation in the EU (European Commission 2020b). It still has to be ratified by the European Parliament and the Council; however, it is important to this project since it covers several key policies of the battery value chain and will shape the production and recycling landscape of LIBs in the future.

If passed, the Proposal would introduce mandatory due diligence for cobalt, natural graphite, lithium, nickel and other chemical compounds based on one or more of these raw materials. The due diligence processes would be based on the OECD Due Diligence Guidance and would include assessment of the impacts on social and environmental risk categories (air, water, soil, biodiversity, human health, occupational health and safety, labour rights including child labour, human rights and community life).

[12] https://www.weforum.org/global-battery-alliance/home (12.01.2021)

With implementation of the new proposal, it would become mandatory to provide information about the carbon footprint for the whole value chain for all batteries with energy content that is >2 kWh (all batteries for BEVs are larger); a benchmark for a maximum carbon footprint of a battery would be set.

Another important feature included in the Proposal is the minimum recycled content to be met in new batteries for Ni, Li and Co. The synergetic measure on the other side of the value chain is the increase in recycling efficiencies that would have to be met (65 % by 2025 and 70 % by 2030 for the overall battery) und the critical materials that would have to be recovered (Cu, Co, and Ni: 90 % in 2026, 95 % in 2030; Li: 35 % in 2026, 70 % in 2030).

To favour second life of batteries, the Proposal encourages increasing data availability. The state of health (SoH) of a battery has to be accessible to allow the battery owner to assess a battery's value and deliver a better basis for further use of the battery. This transparency would increase safety concerning the sale of used vehicles or the battery itself for further use, e.g. as stationary energy storage.

Another measure that would be introduced in the Proposal is the battery passport. The most important information to be provided include:

- Battery type
- Battery composition, including critical raw materials
- Carbon footprint
- Information on responsible sourcing
- Recycled content
- Expected battery lifetime expressed in cycles and reference test used
- Period for which the commercial warranty for the calendar life applies

This information would have to be accessible through a QR-code put on top of the battery cell.

4.3 Mining

This section lists some of the most relevant standards for the sourcing of minerals generally and particularly those minerals used in the mobility sector. In particular, these cover the raw materials applicable for material sourcing for the battery sector (e.g. lithium, cobalt, nickel, and graphite).

4.3.1 Alliance for Responsible Mining

The Alliance for Responsible Mining (ARM) initiative seeks to promote 'inclusive and sustainable development' to legitimise the artisanal and small-scale mining (ASM) sector (ARM 2021a). To achieve this, ARM has set up voluntary standards and certification schemes and promotes the legitimacy of responsible ASM on commodities markets. ARM supports gender equality, diversification, and socially and environmentally responsible production through implementing good practice techniques and certain technological advances.

ARM's most important **Fairmined Standard** certifies ASM gold production and other precious metals. The Standard covers traceability of certified minerals as well as lays out requirements for mining organisations to include worker and environmental protections among other points (ARM 2021b).

ARM has also set up **CRAFT**, the *Code of Risk mitigation for ASM engaging in Formal Trade*, to 'promote sustainable social, environmental and economic development of the ASM sector' by demonstrating that ASM actors conform to due diligence requirements (ARM 2018). The Code seeks to facilitate efforts between legitimate ASM producers and their supply chain actors to interact in formal supply chains. Specifically, CRAFT supports eliminating the worst ASM practices to support ASM miners in understanding international standards. Applicable to extraction of a variety of minerals, CRAFT focuses mainly on 3TG (tin, tungsten, tantalum and gold), cobalt and gemstones (ARM 2020).

4.3.2 Certified Trading Chains (CTC) Certification Scheme by BGR

The Certified Trading Chains (CTC) certification scheme was developed in 2007 for Rwanda and, in an adapted form, for the DRC. Importantly, the scheme acknowledges the specific challenges pertaining to the ASM sector and is hence particularly concerned with feasibility and impact in an artisanal context. It emphasizes process rather than just demanding and certifying certain performance targets. For more information, see the website[13]of the German Federal Institute for Geosciences and Natural Resources (BGR) on certified trading chains.

4.3.3 China Responsible Mineral Supply Chain Due Diligence Management Guide

The *China Responsible Mineral Supply Chain Due Diligence Management Guide* was launched in 2015 by the China Chamber of Commerce for Metals, Minerals and Chemical Importers (CCCMC) in cooperation with the OECD (CCCMC 2016). In following the guidelines, Chinese companies achieve international due diligence standards that can be mutually recognized around the world (OECD 2015). For more information, see the website[14] of the China Chamber of Commerce of Metals.

4.3.4 Cobalt Industry Responsible Assessment Framework (CIRAF)

The Cobalt Industry Responsible Assessment Framework (CIRAF) by the Cobalt Institute is not a standard or certification scheme but a management tool that enables participants in the cobalt industry to prove they are aligned with global best practices in responsible production and sourcing by implementing key state-of-the-art responsible sourcing and production standards.

4.3.5 EITI Standard

The Extractive Industry Transparency Initiative (EITI) is a global standard that promotes transparency and accountability in bringing together the government, companies, and civil society within a country to address how oil, gas and mineral resources are managed. EITI's main principle holds that natural resources belong to the people; gaining and maintaining EITI certification has multi-stakeholder oversight as a pre-requisite. EITI seeks to ensure transparency along the oil, gas, and minerals value chain by disclosing information about contracts and licences, revenues, and economic benefits, among other aspects. Under its eight core requirements, corruption and tax evasion shall be prevented, public and corporate governance strengthened, and inclusive development supported. Fifty-five countries have at some point implemented this standard (EITI 2021).

4.3.6 Extractive Waste Directive

In 2006, the European Commission signed the Directive 2006/21/EC on the management of waste from extractive industries, the 'Extractive Waste Directive', which promotes preventing or significantly reducing adverse environmental effects resulting from extractive industry waste management in the EU. The Extractive Waste Directive particularly addresses environmental risks from wastes that impact water, air, soil, plants, animals and landscapes, as well as risks to human health. The Directive applies to how wastes are managed that were produced through prospecting, extraction including quarrying,

[13] https://www.bgr.bund.de/EN/Themen/Min_rohstoffe/CTC/Concept_MC/CTC-Standards-Principles/ctc_standards-principles_node_en.htmlt (12.01.2021)
[14] http://en.cccmc.org.cn/ (19.03.2021)

treatment and storage of mineral resources (European Commission 2016). For more information, see the EU directive on the management of waste from extractive industries (European Commission 2009).

4.3.7 Fair Cobalt Alliance (FCA)

The Fair Cobalt Alliance (FCA) joins the key stakeholders Huayou Cobalt, Glencore, Tesla, The Impact Facility, The Responsible Cobalt Initiative (RCI) and Sono Motors in a pact to improve working conditions at artisanal and small-scale cobalt mining (ASM) sites in the Democratic Republic of the Congo. The group seeks to implement responsible mining practices (BMI 2020b) by eliminating child labour and increasing household incomes. In this way, the FCA tries to drive the supply of fair cobalt. For more information, see The Impact Facility's website[15] on the Fair Cobalt Alliance.

4.3.8 Global Tailings Review

The Global Tailings Review is a relatively new organization established by ICMM, the UN and PRI (Principles for Responsible Investment) in response to several tailing dam breaks over a short period of time. They created the Global Industry Standard on Tailings Management, a voluntary standard for safer tailings storage facilities, which is directed at the organization operating the tailings storage facility. The requirements are organized around six topic areas:

1. *Affected communities*
2. *Integrated knowledge base*
3. *Design, construction, operation and monitoring*
4. *Management and governance*
5. *Emergency response and long-term recovery*
6. *Public disclosure and access to information*

For further information, see the Global Tailings Review's website[16].

4.3.9 ICMM Mining Principles

The International Council on Mining & Metals (ICMM) wrote out its *Mining Principles* to provide guidance for achieving the UN Sustainable Development Goals (SDGs). The ICMM maintains that successfully fulfilling the SDGs requires minerals and metals that must be produced in a sustainable and responsible manner. These Principles therefore provide guidance and a certification for mining corporations and associations.

Achieving these *Mining Principles* can be certified by a third-party auditor every three years after completing a self-assessment questionnaire. Certification offers more transparency and comparability for stakeholders, investors, customers, etc. Currently the ICMM has 27 company members and 35 association members certified under its Mining Principles.

The following ten points comprise the *ICMM Mining Principles*:

1. *Ethical business – Application of ethical business practices, corporate governance, and transparency systems;*
2. *Decision-Making – Integration of sustainable development in corporate and management strategy;*

[15] https://www.theimpactfacility.com/commodities/cobalt/fair-cobalt-alliance/ (12.01.2021)
[16] https://globaltailingsreview.org/global-industry-standard/ (12.03.2021)

3. *Human Rights, including respect for human rights, culture and traditions of employees and affected communities;*
4. *Risk Management*
5. *Health and Safety*
6. *Environmental Performance, including continual improvement of water consumption, energy use, etc.*
7. *Conservation of Biodiversity, including integrated approaches to land-use planning*
8. *Sustainable Production – contribute to a successful circular economy system of products containing minerals and metals;*
9. *Social Performance – support the development of local communities on social, economic and institutional level;*
10. *Stakeholder Engagement – proactive engagement of all involved stakeholders, including implementation of the Extractive Industries Transparency Initiative (EITI), and the Global Reporting Initiative's (GRI) Sustainability Reporting Standards (ICMM 2021).*

4.3.10 IFC Industry Sector Guidelines

The International Finance Cooperation (IFC) developed *Environmental, Health, and Safety Guidelines* ('EHS Guidelines'; see chapter 4.1.3) that offer a set of references for fulfilling the IFC's definition of 'good international industrial practice' in all industry sectors. The more specific *Industry sector guidelines* for mining, published in 2007, apply to all types of mining operations and mineral processing over all stages of a mining project, excluding the extraction of construction materials that are addressed in a separate *General manufacturing guideline* (IFC 2020). In particular for the mining industry, the guidelines cover acid rock drainage and metals leaching, waste rock dumps, and tailings and include recommendations on mining-specific occupational as well as community health and safety aspects. The recommendations cover such issues as the use of explosives, geotechnical safety and impacts on local communities, for example from tailings dams or land subsidence. They also give recommendations concerning mine closure and post-closure, particularly addressing financial feasibility, though omitting certain relevant aspects for climate change (IFC 2007).

4.3.11 IRMA – Initiative for Responsible Mining Assurance

The Initiative for Responsible Mining Assurance (IRMA) offers a voluntary certification for large-scale mines of all commodity types according to its *Standard for Responsible Mining*. This set of criteria certifies individual mines, not mining companies, based on requirements for: 1) business integrity, 2) planning for positive legacies, 3) social responsibility and 4) environmental responsibility (IRMA 2021a). The Standard was developed in a multi-stakeholder process of 'mining companies, mining material buyers, NGOs, affected communities, and organised labour' (IRMA 2021b). Through certification, the performance of all types of mining operations, including surface, underground or solution mining, are verified by an independent third party for demonstrating good practice and industry leadership from sustainable and responsible production methods. With the certification, consumers can also see that products containing IRMA-certified materials were sourced responsibly. Lithium, cobalt, and nickel are all part of the standard.

4.3.12 London Metal Exchange Responsible Sourcing Requirements

The London Metal Exchange (LME) requires responsible sourcing from all its listed brands. They rest on four core principles: 'the combination of transparency and standards; non-discrimination between large-scale mining (LSM) and artisanal / small-scale mining (ASM); adherence to well-established work in the sector; and a pragmatic and clear process.' (LME 2019)

4.3.13 OECD Guidance Documents

The Organisation for Economic Co-operation and Development (OECD) maintains its *Due Diligence Guidance for Meaningful Stakeholder Engagement in the Extractive Sector* to include various stakeholders – e.g. local communities, ASM, and governments – in corporate planning and decision-making for oil, gas, or mineral extraction operations (OECD 2020a). Based on the OECD's *Guidelines for Multinational Enterprises*, the Due Diligence Guidance provides a framework for all relevant stakeholders to be engaged in management and practical processes throughout an endeavour, from project planning to business operations. Stakeholders can then remain informed and more easily take part in decision-making processes to help companies mitigate adverse impacts from their extraction operations, in particular human rights violations or conflicts with indigenous communities. The guidance offers a framework, practical tools, and approaches for management and on-site personnel.

The OECD's Due Diligence Guidelines propose seven 'key steps to ensure meaningful stakeholder engagement': a) position stakeholder engagement strategically, b) understand the local and operating context, c) identify priority stakeholders and interlocutors, d) establish support systems, e) design appropriate and effective engagement activities, f) ensure follow through on commitments, and g) monitor and evaluate engagement activities (OECD 2020b, 2020a).

The OECD Due Diligence Guidance for Responsible supply Chains of Minerals from Conflict-Affected and High-Risk Areas also includes the ASM sector and gives several basic principles on how to interact with this sector (OECD 2016).

4.3.14 Responsible Cobalt Initiative

Significant for the raw materials in batteries, the Responsible Cobalt Initiative allows Chinese and other stakeholders along the cobalt supply chain to collaborate in taking responsibility for environmental and social risks. The China Chamber of Commerce for Metals, Minerals and Chemical Importers launched the initiative in 2016 with support from the OECD. In 2017, the RCI had 24 members, including Apple, BMW, CATL, Dell, HP, Huawei, Sony, Samsung SDI, LG Chem, Hunan Shanshan, L & F, Tianjin B & M and Huayou Cobalt. The initiative aims at addressing environmental and social risks along the cobalt supply chain, with the elimination of child labour as one of its primary goals. It is currently developing an auditing scheme and considering local development projects in the DRC. For more information, see the website[17] of the Responsible Cobalt Initiative.

4.3.15 Responsible Minerals Initiative

The Responsible Minerals Initiative (RMI) offers companies different tools to improve their due diligence schemes for their supply chains and responsible sourcing of minerals. Among the RMI tools, the Conflict Minerals Reporting Template (CMRT) and the Cobalt Reporting Template (CRT) provide downstream companies with free, standardised reporting forms to share information about supply chains. These templates allow information about mineral origins or the refiners and smelters to be shared easily. This transparency also helps to identify smelters and refiners that have not yet been audited in the RMI Responsible Minerals Assurance Process (RMAP). For more information, see the Responsible Minerals Initiative's website[18].

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[17] https://respect.international/responsible-cobalt-initiative-rci/ (12.01.2021)
[18] http://www.responsiblemineralsinitiative.org/about/faq/downstream/what-is-the-cmrt/ (12.01.2021)

4.3.16 The European Raw Materials Alliance (ERMA)

To promote economic resilience in the EU, the European Raw Materials Alliance (ERMA) confronts the EU difficulties to secure access to sustainable raw and advanced materials as well as the necessary processing expertise. The initiative is organized under EIT RawMaterials, which is part of the European Institute of Innovation and Technology (EIT). ERMA activities, separated into the main workstreams 'value-chain-specific consultation processes' and 'investment channels for raw materials projects', help to diversify supply chains and attract investment by supporting innovation and training. ERMA's support for recovery and recycling of critical raw materials also contribute to promoting the Circular Economy for products such as electric vehicles, clean technologies and hydrogen equipment. In particular, ERMA promotes innovations, infrastructure, investment and industrial production that are environmentally sustainable and socially equitable. For more information, see the website[19] of the European Raw Materials Alliance.

4.3.17 The World Bank Climate-Smart Mining Initiative

The World Bank has set up the Climate-Smart Mining Initiative to address issues such as high energy consumption as well as social and environmental impacts coming from the mining sector. The Initiative recognises the need for developing countries to equitably benefit from the increase in demand for minerals they produce that support the transitions in mobility. Therefore, the Initiative focuses on four areas: 1) climate mitigation, 2) climate adaptation, 3) reducing material impacts and 4) creating marketing opportunities (The World Bank 2020). Part of the climate Climate-Smart Mining Initiative is also Forest-smart mining, which aims to prevent 'deforestation and supporting sustainable land-use practices; repurposing mine sites' (The World Bank 2019) and also includes ASM.

4.3.18 Towards Sustainable Mining

The Mining Association of Canada maintains its Towards Sustainable Mining (TSM) sustainability programme that assesses member mining companies in all countries in which they operate based on 30 performance indicators. TSM guides companies in managing their environmental and social responsibilities. Originally developed for Canadian companies, TSM has spread internationally and is adopted by several other mining organisations, including the Finnish Mining Association (FinnMin), the Argentinean Chamber of Mining (Cámara Argentina de Empresarios Mineros), and the Botswana Chamber of Mines (The Mining Association of Canada 2019a).

The TSM programme provides tools and guidelines in three main areas: 1) communities and people, 2) environmental stewardship, and 3) energy efficiency. These areas are further broken into eight operational areas – i) indigenous and community relationships, ii) energy and GHG emissions management, iii) tailings management, iv) biodiversity conservation management, v) safety and health, vi) crisis management and communications planning, vii) preventing child and forced labour, and viii) water stewardship – each of which having a TSM Assessment Protocol that supports companies in developing, measuring, and reporting their management systems and performance (The Mining Association of Canada 2019c).

The eight TSM Assessment Protocols each describe how to identify good practices, define criteria and indicators that facilitate companies in measuring their own performance, and offer case studies of successful TSM certification. Framework documents are published for some Protocols that more

[19] https://erma.eu/ (12.01.2021)

precisely describe the commitment or offer guidance for aspects for which there are no protocols, for example regarding mine closure (The Mining Association of Canada 2019b).

4.4 Recycling

The most recent research uncovered no international standards for recycling LIBs. However, the EU has several regulations in place that mention recyclers. The Battery Directive, which is essential for the battery recycling, is currently under review, and a new proposal for revisions has recently been submitted by the European Commission (see chapter 4.2.5). Two other EU directives discussed below are also relevant for waste management of LIBs from passenger cars: the Waste Electrical and Electronic Equipment (WEEE) Directive and the End-of-Life Vehicles (ELV) Directive.

4.4.1 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (‘Basel Convention’) is an international environmental agreement that has established environmentally sound waste management and regulates the control of transboundary hazardous waste shipments (Basel 2011). LIBs at their EoL also fall under the Basel Convention, which makes it difficult to ship them around the world as the process involves many necessary authorisations (WEF 2020b).

4.4.2 ELV Directive

Under the End of Life Vehicles Directive (2000/53/EC) of the European Union, which is currently under revision, vehicle manufacturers have extended responsibility for the vehicles they produced and for the vehicular components after use (Ramoni and Zhang 2013). This Directive thereby requires vehicle manufacturers to physically take back their products so that the items may be reused, recycled or remanufactured. Alternatively, manufacturers may delegate their responsibility to a third party (Ellingsen and Hung 2018, EEA 2018).

Following the guidelines of the ELV Directive, treatment begins with collecting and deregistering the end-of-life vehicle. Once a vehicle is dismantled, components are collected for further processing, such as batteries containing hazardous materials and other recyclable or reusable components like engines, tyres and bumpers (e.g. Sakai et al., 2014).

4.4.3 Collection, Logistics, Pre-treatment, Downstream treatment of WEEE (EN 50625-1:2014)

The purpose of this European Standard for Collection, Logistics, Pre-treatment, Downstream treatment of WEEE (EN 50625-1:2014) is to support institutions to:

- carry out effective and efficient treatment and disposal of waste electrical and electronic equipment (WEEE) in order to prevent pollution and reduce emissions;
- promote increased mechanical recycling;
- support high quality recycling processes;
- prevent improper disposal of WEEE and its fractions;
- ensure human health and safety and environmental protection; and
- prevent shipments of WEEE to suppliers whose operations do not comply with the requirements of this normative requirements of this normative document or comparable specifications.

This EU standard is focused on WEEE, but also includes batteries generally.

5 Narrative Analysis

In the RE-SOURCING project, a narrative analysis was conducted in autumn 2020 for the three sectors in the focus of the project: renewable energy, mobility and electronic and electric equipment. The results of the narrative analysis of the online discourse addressing responsible sourcing in general and specifically for the renewable energy sector are explained and visualised in the State of Play report on renewable energy (Kügerl 2021). The results of the narrative analysis on responsible sourcing in general are also included in the annex below.

The narrative analysis investigated the selected terms in the context of the mobility sector in the world wide web, with the aim to provide feedback on whether these terms are present in public discourse and the engagement. The investigation modelled the drivers of market behaviour of these narratives. One result is the emotional response of the selected narratives in the web.

The analysis was carried out by the external company Significance System. It is a service provider specialising in the analysis of 'behavioural interactions with online content, to model human interaction' (Significance Systems 2019).

The results were analysed from two perspectives:

Is the topic already under discussion?

- *If so: who are the main actors dealing with this topic? What reactions does the topic trigger in the population (world wide web)?*

Is a term not yet a topic of discussion and not yet considered by the public?

- *If so: It needs to be identified whether it is important to 'push' this issue in order to promote responsible sourcing.*

In this project, narrative analysis was chosen as a new and innovative approach and is only one among many sources in the research on the mobility sector. However, the results of this narrative analysis are not the deciding factor for further project work.

5.1 Methodology

'Narratives' in this context are key words, phrases or brands. The 20 narratives used in this study for analysing the mobility sector were chosen based on the project team's knowledge of the topic, the results from initial research, and feedback from Platform Steering Committee members and company representatives.

The list of narratives used for the analysis are provided in Table 7. Terms in quotation marks indicate the exact syntax and wording of the phrases for the search algorithm.

Table 7: Selection of 20 narratives for the mobility sector

"automotive industry" sustainable procurement	"lithium-ion battery" recycling
"battery metals" mining in Europe	"Mandatory recycling rates" lithium
"cell manufacturing" battery responsible supply chain	"Natural graphite" environmental impact

"global warming potential" battery manufacturing	"Global Battery alliance"
"Graphite mining" dust emissions	"European battery alliance"
"labour conditions" DRC cobalt	"synthetic graphite" environmental impact
"lithium-ion battery" informal recycling	"automotive industry" responsible raw material supply
"lithium mining" water scarcity	Nickel Indonesia "export ban"
"Lithium mining" environmental requirements	"Battery grade" nickel
"Lithium mining" social requirements	"responsible recycling" batteries

The results of a narrative analysis allow the terms – the narrative – to be classified into one of the following four categories (Significance Systems 2021):

***Timeless**: Timeless narratives are the most powerful type of narratives, creating long-term and deep engagement. This applies to about 5 % of all narratives in the Significance Systems database. These timeless narratives are characterised by being predictive of future behaviour; namely there is a high likelihood the narrative will remain powerful over time and thus significantly influence those who engage with it.*

***Transformational**: The smallest group of narratives, only 2 %, are transformational narratives. These generate a lot of engagement with a large group of people and represent a transformation in global opinion with respect to the narrative tested. Transformational narratives are in a state of movement, e.g. to become more important or negative.*

***Tribal**: Tribal narratives are narratives that relate to a very specific issue that creates a lot of engagement, but only from a very small number of people. About 8 % of narratives in the Significance Systems database are tribal.*

***Transient**: Around 80 % of all narratives ever tested in the Significance Systems database are transient. Transient means they are not often addressed in media and they do not have the power to engage.*

For each narrative, the emotional response associated with the narrative was also identified. This is called affect, and for timeless narratives it is predictive of future emotional responses. Information was also obtained on the most influential media and content. The media power index is a ranking of 'media voices according to their power to lead debate, shape perception, and drive market performance in terms of preference and desirability' (Significance Systems 2020). Content refers to individual pieces of content, such as articles, posts, etc. and is again ranked according to its intrinsic power, i.e. the content's 'ability to drive market performance against preference and desirability' (Significance Systems 2020). This information is useful to evaluate the key players and countries driving a certain narrative, but also to determine whether the results are actually relevant for this study (Kügerl 2021).

5.2 Results

The narrative analysis for the RE-SOURCING project was conducted to assess whether the selected topics are relevant in the current global media landscape. The following Table 8 and Figure 21 present the results of the narrative analysis on the mobility sector.

Table 8: Categorisation of the selected narratives into four narrative groups

"automotive industry" sustainable procurement	"lithium-ion battery" recycling
"battery metals" mining in Europe	"Mandatory recycling rates" lithium
"cell manufacturing" battery responsible supply chain	"Natural graphite" environmental impact
"global warming potential" battery manufacturing	"Global Battery alliance"
"Graphite mining" dust emissions	"European battery alliance"
"labour conditions" DRC cobalt	"synthetic graphite" environmental impact
"lithium-ion battery" informal recycling	"automotive industry" responsible raw material supply
"lithium mining" water scarcity	Nickel Indonesia "export ban"
"Lithium mining" environmental requirements	"Battery grade" nickel
"Lithium mining" social requirements	"responsible recycling" batteries

Legend:

orange = transformational narrative
grey = tribal narrative
yellow = narratives falling between the categories transient and timeless
white / no highlight = transient narrative

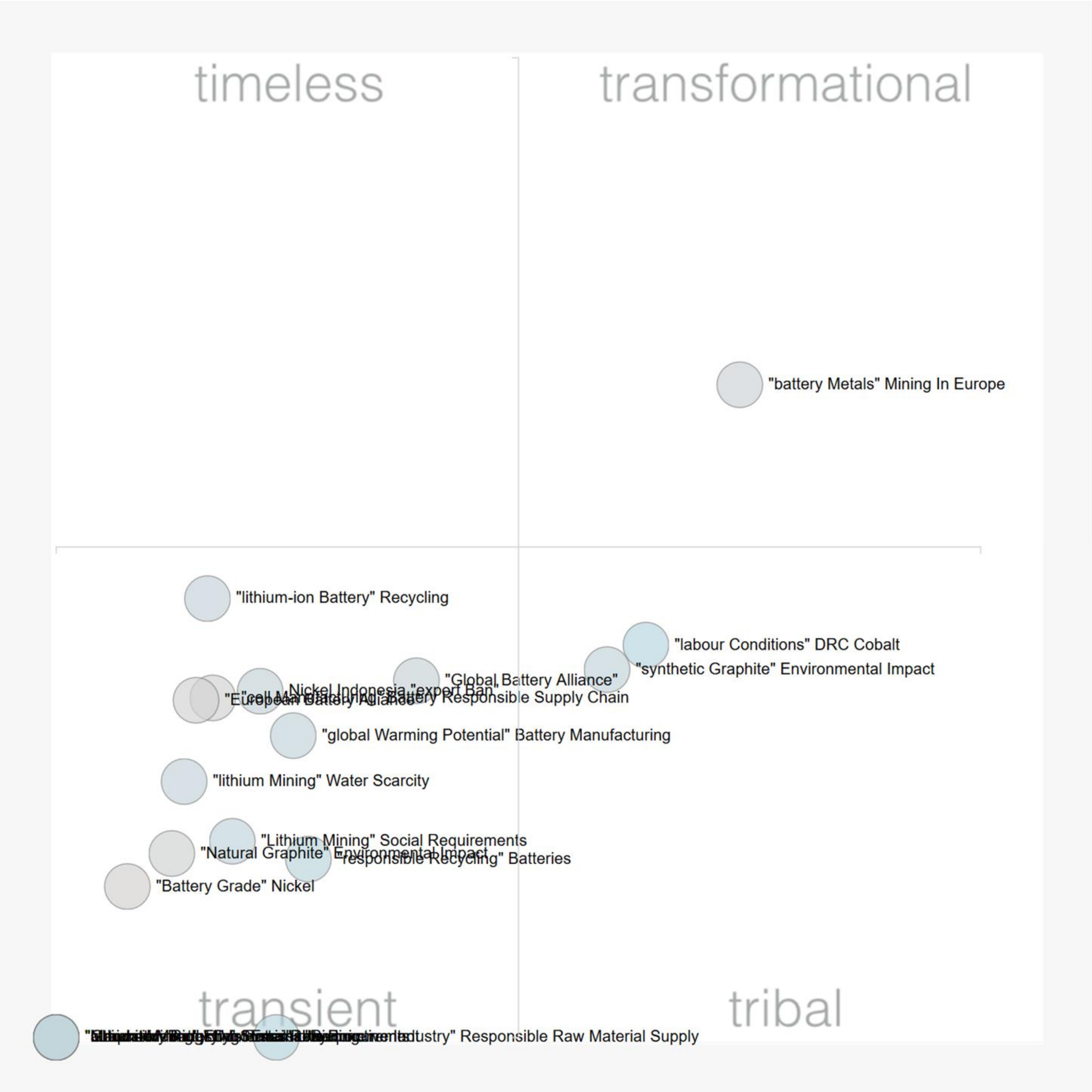

Figure 21: Categorisation of the selected narratives into four narrative groups

From these results, what stands out directly is that none of the chosen narratives fall into the timeless category. This can be explained on the one hand by the fact that the selected narratives are very long (more than three words). On the other hand, these narratives are very detailed and concrete (e.g. *"lithium mining" environmental requirements*) (Significance Systems 2021).

Also, immediately obvious is that three out of 20 chosen narratives were classified as transformational or tribal. The narrative *"Battery metals" Mining in Europe* was classified as transformational, which is highlighted orange in the table. Two narratives were classified as tribal *("Labour conditions" DRC Cobalt*; *"synthetic Graphite" Environmental impact*) and visualized in grey in the table. One other narrative, *"lithium-ion battery" recycling*, was classified closely to the timeless category.

The remaining narratives, which in Table 8 are not colour-highlighted, were categorized as transient. This means that these narratives are not often addressed in the media. For the RE-SOURCING project, this might be an indicator that further engagement is needed in these aspects within the Roadmap to strengthen the narratives.

In particular, the transformational narrative *"battery metals" Mining in Europe* has the potential to become more prominent in the public awareness. The following Figure 22 presents the emotional response of the narrative, indicating a high share of positive feelings (in green). Negative emotions are coloured in red. The intensity of the colour reflects the intensity of the emotion. The width of each arc reflects the degree to which the named emotion contributes to the overall emotional response. Broad emotions, such as love, are closer to the centre of the chart. The more subtle emotions that contribute to those broad emotions, are shown in the concentric rings further out. Starting from the centre, each ring shows a further level of detail (Significance Systems 2020).

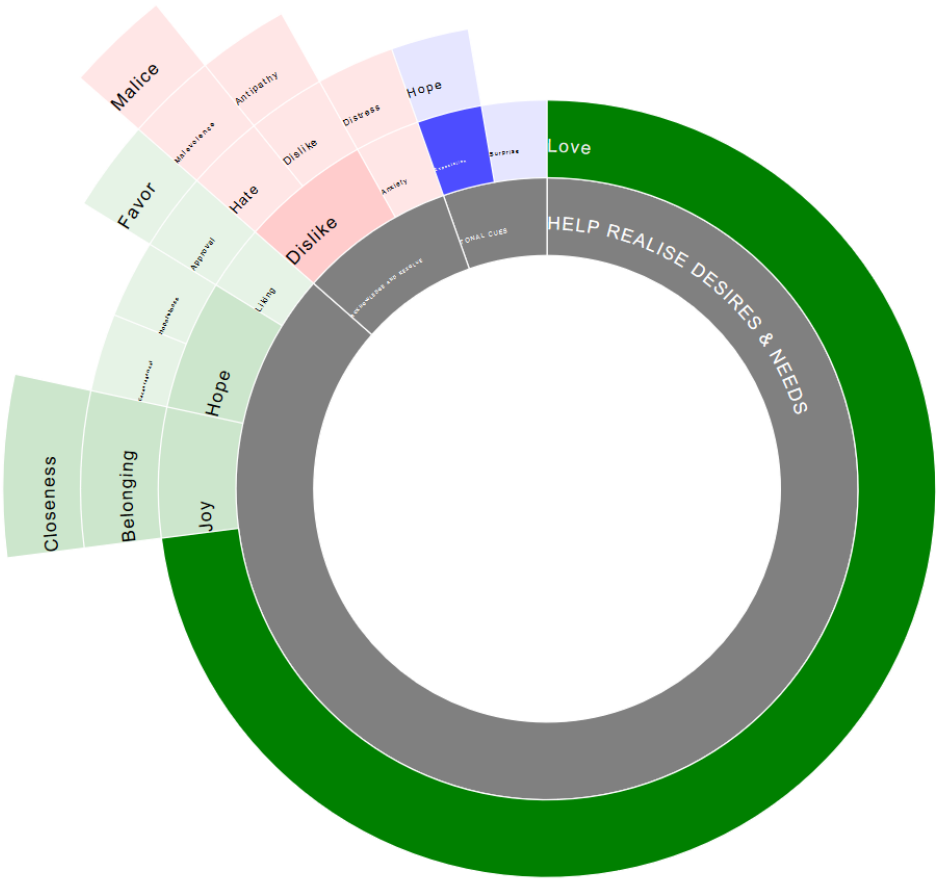

Figure 22: Emotional response to the narrative "battery metals" mining in Europe

Looking deeper in the narrative analysis, it can be realized that these positive emotions are only driven by organizations interested in investing in battery metals mining. The results of the analysis of this specific narrative were driven by the content on four websites: 50 % by newsfilecorp.com, 25 % by northminer.com and 13 % by oilprice.com and spglobal.com. In other words, this narrative is strongly driven by investor interests; the topic behind the positive emotional response is driven by the relationship to lithium.

The narrative *"lithium-ion battery" recycling* is categorised as transient – yet close to timeless. In contrast to the narrative previously discussed, the emotional response to this narrative (see Figure 23) is associated with a high share of expectations, in purple. The results for this narrative were driven by the news media, in particular 26 % from *Area Development,* a magazine covering corporate site selection and relocation. Wikipedia.org gave 11 % of the results, followed by globenewswire.com (10 %) and nature.com (10 %). Other smaller actors, such as recellcenter.org, were also sources for the results. Overall, this narrative reflects passive, positive engagement. These kinds of narratives are often long-lived, but vulnerable to apathy and unanticipated disruption. They may not have the strength to survive rapid, transformative change.

Figure 23: Emotional response to the narrative "lithium-ion battery" recycling

This narrative analysis research indicates for the project's Roadmap process which selected narratives might be strengthened in the future. To achieve this, relevant narratives could be linked to timeless and other strong narratives, like *ESG* (environmental, social, governance) *mining*. By publishing and sharing information online in connection with strong narratives, more attention and engagement could be achieved for the targeted narrative.[20]

[20] As a concrete example for how to strengthen a narrative: 1. look at which articles and which author a strong narrative (e.g. ESG) is based on; 2. contact this author and discuss both the strong narrative and the weaker narrative that should be strengthened to achieve a publication on both topics.

6 Vision

The Vision of the mobility sector represents the final step of the Roadmap to be achieved by 2050. This chapter provides a first overview of the goals for the mobility sector that the RE-SOURCING project aims to help achieve. The Vision is based on the concepts of planetary boundaries and strong sustainability, providing essential guidelines for the preservation of natural capital. The Roadmap to be produced over the course of the RE-SOURICNG project will provide a step-by-step approach towards achieving the Vision.

At the beginning of the project, it was agreed with the project team, Advisory Board and Platform Steering Committee to focus efforts in the mobility sector on three value chain steps of Li-ion batteries – mining, cell production and recycling of Li-ion batteries – and concentrate on the four minerals lithium, cobalt, nickel and graphite. The Vision will likewise address these steps and minerals.

The development of an overarching vision forms the basis and at the same time the long-term target for further steps in the RE-SOURCING project work on creating a Roadmap on responsible sourcing in the mobility sector. The State of Play document presented here forms the basis for this process.

Having a Vision, to be achieved by 2050, for the 'ideal' supply chain in the selected value chain steps (mining, cell production, recycling) is critical for further developing the Roadmap. The ultimate goal of the RE-SOURCING Roadmap will be to achieve this Vision. Therefore, the Roadmap shall provide a plan and strategy for policymakers and companies on how to realise this vision, with the focus on European industry.

The Vision is based on two basic concepts: planetary boundaries and strong sustainability. The concept of *planetary boundaries* consists of nine thresholds within which humanity may act in a safe manner without causing catastrophic environmental change. The nine defined planetary boundaries are climate change, stratospheric ozone, biogeochemical nitrogen cycle, phosphorus cycle, global freshwater use, land system change, rate of biological diversity loss, chemical pollution and atmospheric aerosol loading. For the last two boundaries, no suitable threshold has yet been identified (Rockström et al. 2009).

The concept of strong sustainability focuses on the substitutability of natural capital. Strong sustainability argues that natural capital cannot be completely substituted by manufactured capital. It follows that certain human actions can entail irreversible consequences (Pelenc et al. 2015).

In Chapter 4 a lot of standards and initiatives are listed which are mainly in line with the Sustainable Development Goals (SDGs). These SDGs need to be implemented by 2030. In comparison, the RE-SOURCING Roadmap aims at 2050, by which time the goals can and should be set higher. Furthermore, studies have found that the SDGs support the concept of weak sustainability as the goals are currently achieved by causing further environmental degradation (Jain and Jain 2020; Tost et al. 2018).

The strong sustainability concept, which will be one basis for the RE-SOURCING Vision in the Roadmap, is supported by the World Business Council for Sustainable Development (WBCSD). In 2010, The WBCSD published the "Vision 2050", which contains many of the desired goals in the mobility sector. It also sets out a Roadmap for achieving these goals. This vision is currently under review ("Vision 2050

Refresh") and pressing topics such as social tensions and environmental impacts will be brought further into focus (WBCSD 2020).

In addition to these concepts, the Vision that the RE-SOURCING project develops here is based on international cooperation as well as harmonised reporting systems, with clear global criteria for responsible and sustainable practices. The Vision's detailed targets for the mobility sector are also transferrable to other sectors; however, these targets are not always easy to measure. Figure 24 clusters the Vision's targets according to the three pillars of sustainability: environmental, social, economic. Furthermore, the targets are first grouped by issues across all value chain steps and then focused on the three selected supply-chain stages in the mobility sector (mining, cell production, and recycling). The targets listed in Figure 24 are specified here in plain text.

Targets across all value chain steps included under the:

Environmental pillar of sustainability: limiting climate change to 1.5°C; carbon-neutral production and transport; net-positive environmental impact; net-positive contribution to biodiversity; zero pollution of land and sea; zero harmful emissions; use of renewable energy sources and resource efficiency

Social pillar of sustainability: zero human rights violations; gender equality in all stages of the supply chain; elimination of poverty and hunger; secure access to food, clear air and water, sanitation, health care; meaningful stakeholder engagement; support of local development; fair compensation for land-use; respect for land rights; occupational health and safety; community health and safety; local recruitment; knowledge sharing and training

Economic pillar of sustainability: sustainable and responsible investments; fair wages; transparency; zero financial crime; fair compensation for land-use, minerals, etc.; "unsustainability is unprofitable"; companies accept their responsibility; absolute decoupling of economic growth from resource consumption and environmental impact; level playing field.

In the **mining and mineral processing** step, the following targets are part of the vision:

Environmental pillar: zero hazardous tailings discharge; re-use of tailings and waste rock; better-than-before reclamation; efficient processing, including energy and water efficiency, improved recovery; efficient use of deposits; remediation of abandoned mines

Social pillar: formalisation of ASM sector and full integration in the supply chain; cooperation between LSM and ASM; conflict free mineral supply chains; sharing of infrastructure; ensuring water availability and quality for neighbouring communities; free prior-informed consent

Economic pillar: proof of origin and traceability of minerals; transparent granting of mining licences; use of new technologies and automation; multi-stakeholder governance; local content in value chain

In the **cell production** step, the following targets are identified:

Environmental pillar: eco-design and collaboration of manufacturers and recycling plants; responsible use of toxins, use of alternative substances where possible; recovery of solvents; increased input of secondary materials; use of renewable energy; reduced energy input

Social pillar: local value creation; occupational health and safety

Economic pillar: abandonment of 'the cheaper, the better' philosophy; support responsible production practices upstream; local sourcing where possible; process optimization

The **recycling** step includes the targets:

Environmental pillar: circular economy with closed loop and zero waste culture; recycling of all recyclable materials used in Li-ion batteries; evaluate used Li-ion batteries regarding second life opportunity; eco-design and collaboration of manufacturers and recycling plants; no dumping of toxic materials in landfills

Social pillar: maintaining air quality; maintaining water quality; health and safety in collection, transport and recycling; occupational health and safety

Economic pillar: financially more attractive than primary raw materials; landfilling forbidden; innovation-friendly environment; adequate legal basis for recycling; local recycling and reuse

These targets assume that battery-electric vehicles will be the main technology for passenger road transport and the energy will be provided by renewable energy.

To encourage strong sustainability, the main environmental goal is clear – to limit the temperature rise to at most 1.5°C. Temperature rising beyond that are scientifically assessed as permanently damaging the climate system. Strong measures are required to limit GHG emissions. This requires successful international cooperation and harmonisation of standards, which is the basis for the Vision in this roadmapping process.

It should be emphasised that the authors do not advocate the exclusion of certain actors within the supply chain due to prevailing problems (e.g. ASM). The RE-SOURCING project aims to initiate a global, joint effort to alleviate and resolve problems along the battery supply chain for the mobility sector.

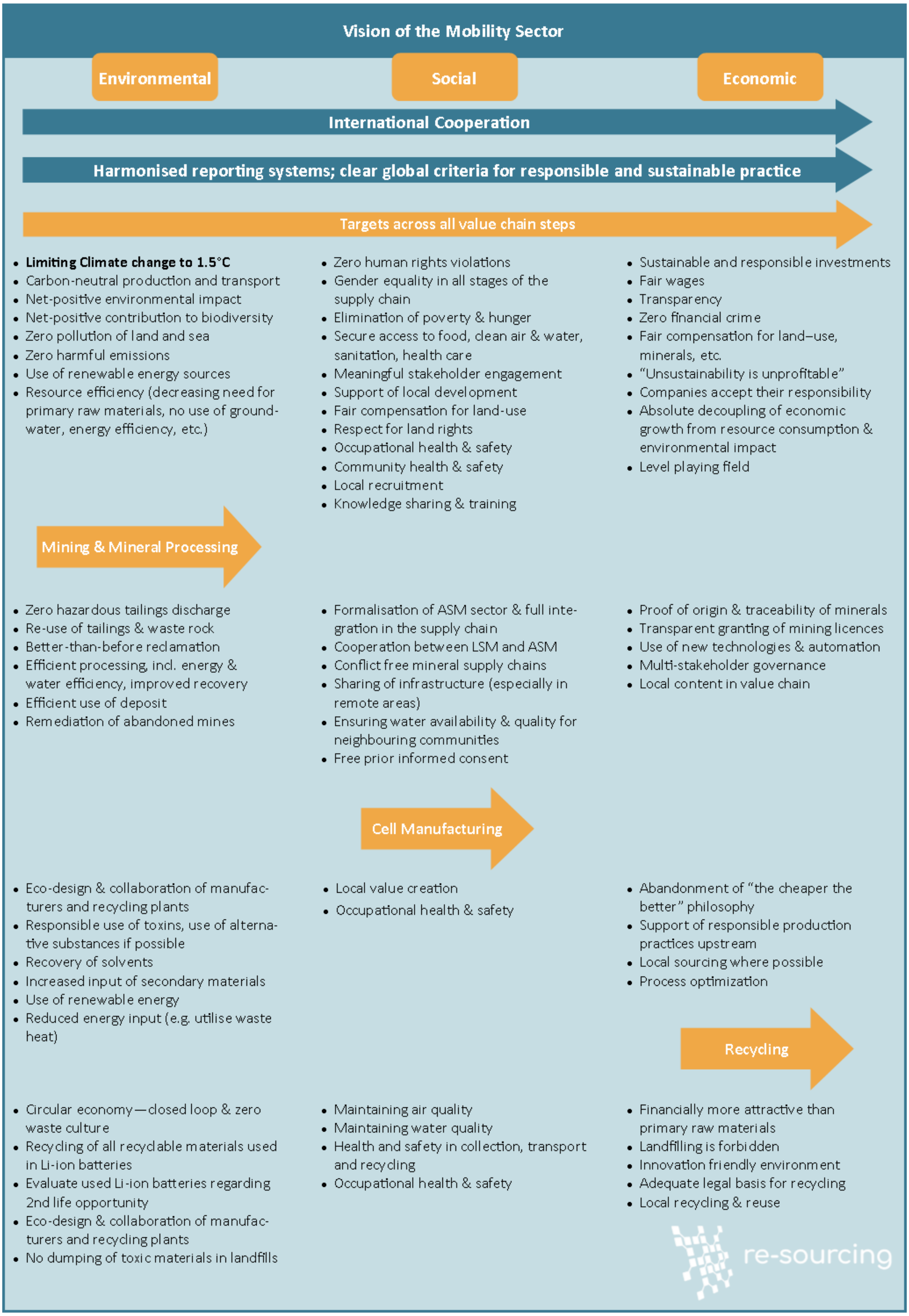

Figure 24: Vision for the Mobility Sector by 2050, based on (Kügerl 2021); (WEF Mining & Metals 2014) (WBCSD 2020) (Franks 2015)

7 Gap Analysis and Focus Areas for the Roadmap Process

7.1 Gap Analysis

The gap analysis evaluates missing links between existing standards and sustainability schemes and the Vision developed in the RE-SOURCING project. The first gap identified arises from the large number of guidelines applicable to the mining sector – a harmonisation of standards and an overarching international framework is required. Such an international framework is also necessary for the battery cell production and their collection and treatment in the end-of-life stage. However, currently there are not many initiatives and standards focused specifically on the production and recycling steps.

Other very important gaps can be found in the issues of environmental sustainability and resource efficiency. Considering the sales increase of battery electric vehicles, the associated increase in demand for raw materials needs to be addressed. Also, proper collection, transport, storage and recycling of spent batteries is essential.

As part of the RE-SOURCING project, a gap analysis of the mobility sector was carried out. Procedures analogous to the RE-SOURCING assessment of the renewable energy sector were applied to ensure a uniform procedure within the project.

After analysing existing standards and initiatives (chapter 4) and establishing the Vision (chapter 6), a gap analysis was conducted to identify what needs to be done to achieve the vision for the mobility sector in 2050. Many of the above-described standards aim to support reaching the SDGs. This shows that many actors are committed to achieving these goals.

To analyse gaps in the existing initiatives applicable to mining, this analysis used a 2017 study by the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe; Germany's Federal Institute for Geosciences and Natural Resource) that compares prominent mining standards (BGR 2017). From the German study it can first be noted that no single initiative covers all 108 of the BGR's subtopics. Other topics are not covered by any of the four reviewed standards (IRMA, IFC, ICMM, and GRI) or only by one standard.

The following 11 issues are not covered in the four reviewed standards: 1) women rights, 2) alluvial mining, 3) conflicts with agriculture, 4) conflicts with large scale mining (LSM) or indigenous populations, 5) extortion, 6) money laundering, 7) mergers and acquisitions, 8) divestment, 9) pricing and price premiums, 10) production plan, and 11) responsible person for the standard. Looking at the topics addressed by only one of the four standards analysed, it can be seen that a combination of the four standards would result in a very comprehensive scheme covering 97 out of 108 parameters.

Some of the 11 topics missed by the four standards discussed above are covered in the OECD Due Diligence Guidance for Responsible Mineral Supply Chains as well as in standards based on this guidance (e.g. LME Responsible Sourcing, Fairmined). The OECD provides guidelines on the risks of financial crimes, including money laundering, bribery, or tax evasion. It also addresses issues related to ASM, such as cooperation between LSM and ASM activities and the integration of ASM into formal supply chains. Furthermore, the declaration of origin and the risk of its misrepresentation is covered (OECD 2021, OECD 2016).

In the cell production and recycling step there are only a few initiatives and regulations for responsible sourcing and production so far. Ambitious guidelines and regulations need to be developed here.

7.2 Focus Areas for the Roadmap Process

Some overarching issues relevant for achieving responsible sourcing might become relevant as the RE-SOURCING team develops the Roadmap over the coming year.[21] In particular, several issues need to be addressed in more depth: a level playing field, a global due diligence initiative, the harmonization of sustainability requirements, responsible procurement, and an overall strengthening of the recycling sector, especially looking at recycled content of traction batteries and resource efficiency. These overarching themes are briefly summarized here and will feed into the Roadmap process.

7.2.1 Level Playing Field

A level playing field is the basis for a globally sustainable market. In this target state, producers who do not act sustainably are excluded from the market. A level playing field requires globally binding, unified framework conditions. For example, recycling can be promoted by setting obligatory rates of recycled content in new products, as proposed for the revised EU regulation on batteries. Also, harmonization and mutual recognition of standards and certifications are essential for this approach.

Many of today's issues in the value chain arise from asymmetries in regulation in different countries. Countries with high environmental & social standards are more expensive when it comes to production. While one country might for instance allow offshore tailings disposal (e.g. discharge into rivers or submarine disposal), creating a cost advantage, others forbid this practice leading to higher costs for mining waste management or even to not mining certain deposits at all.

The long-term aim should be that globally negotiated and agreed upon standards are applied. Cost advantages at the expense of social and environmental criteria should not be present. Having no options to cut costs on sustainability issues could even encourage cost savings through productivity increase to gain a competitive advantage.

7.2.2 Global Due Diligence

A global due diligence approach across all sectors and value chain steps would highlight the challenges across all the pillars of sustainability as well as in all value chain steps. "Due diligence is the process enterprises should carry out to identify, prevent, mitigate and account for how they address […] actual and potential adverse impacts in their own operations, their supply chain and other business relationships […] (OECD 2020c).

With a global approach following the OECD Due Diligence Guidance (see chapter 4.1.7 for a summary), the negative impacts along the entire value chain can be identified and addressed at an early stage. Mandatory due diligence is already introduced in in the EU regulation on conflict minerals directly

[21] The roadmap will be developed by summer 2021 with external actors of the lithium-ion battery value chain in interviews and workshops.

referring to the OECD guidelines. Moreover, the newly proposed EU Battery Regulation also introduced this concept for raw materials in industrial and EV batteries (EC 2020b).

The approach of transparency with a proof of origin is also frequently mentioned. Usually, this aspect is covered by standards addressing conflict minerals (e.g. conflict-free gold standard, Responsible Jewellery Council, Fairmined; see chapter 4.3) which are relevant in the jewellery sector. However, this kind of traceability scheme needs inspectors to be located directly at the mining operation in order to be able to certify the origin of the raw material. The same applies to the traceability of raw materials along the supply chain when using blockchain: a supervisor at the mine must assess the production processes, certify the materials according to a specific scheme, and register them in the blockchain system. The core of these approaches is knowing at each step of the value chain where the mineral came from. However, documenting this information is difficult in practice, as different raw material flows are combined in the next step of a value chain (e.g. raw material from different origins come together in the refining step). It needs to be pointed out, that the main aim should be a sustainable and responsible conduct along the whole supply chain. The idea of traceability can be a means to achieve that but must not necessarily be the most suitable pathway in terms of cost benefit ratio.

Within the course of the expert consultation of the renewable energy sector, information was collected on new approaches. For example, IRMA is currently in the process of publishing a *Chain of Custody Standard*. This standard was developed to provide the base-level requirements for tracing any mined material from the mine through the downstream chain of custody to the end consumer. The IRMA Chain of Custody Standard will, as needed, be supplemented by Annexes specifying additional guidance for specific mineral supply chains. In addition, this standard has been developed to work in concert with existing and emerging traceability services and technologies (e.g., blockchain, mineral ID scanning, testing, etc.). It also can be used to help validate key systems and documentation through on-site audits that are associated with secure ledgers and testing results. This Chain of Custody Standard is intended to be compatible with other standards and programmes that promote responsible sourcing of mined materials (e.g. ResponsibleSteel, Responsible Jewellery Council). IRMA will work to adapt expectations when coordinated with other systems working towards the common goal of conveying value for responsible practices at the mine level down the chain to consumer-facing products (Kügerl 2021).

7.2.3 Harmonization of Sustainability Requirements

One of the most important aspects for improving the mobility sector, as well as other industry sectors, is creating a common framework for and harmonisation of the sustainability requirements in the different standards and initiatives – especially in the mining sector. The adoption of many standards as possible is not an appropriate solution, neither for the mining companies that need to apply them nor for the customers who need to ensure that all responsible sourcing requirements are met. Sustainability schemes in the mining sector often have various scopes and foci, yet they often differ in the most basic definitions like for the term *protected area* (BGR 2017). A positive example for such an international framework is the ILO conventions and recommendations that are widely accepted across countries and industries.

The standards and initiatives that pertain to battery cell manufacturing (e.g. the Battery Pass by the Global Battery Alliance or the proposal for a regulation of the European Union; see Chapter 4.2) are comparatively few and still under development. It remains to be seen how these approaches will develop and be harmonised under the rapid growth of the cell production.

However, a number of non-sector specific international standards exist addressing various aspects of the manufacturing process, e.g. the ISO-standards for environmental (14001), occupational health & safety (45001), and energy (50001) management. Labour guidelines are covered by the ILO, EHS guidelines are provided by the IFC, and the SDGs and OECD guidelines for multinational enterprises are general governance frameworks (Kügerl 2021).

7.2.4 Responsible Procurement

The link between the individual stages of the supply chain is created by procurement, which is incidentally addressed by an ISO standard, ISO 20400, to provide internationally valid guidelines for procurement processes of all types of organisations (see chapter 4.1.6). Other global or national initiatives addressing procurement often focus only on public procurement, e.g. the UNEP Sustainable Procurement Guidelines, or the Sustainable Procurement Guidelines of the Australian government. Some international companies have internal regulations on how procurement is managed in a sustainable and responsible manner and publish their procurement standards on their website, e.g. Umicore (UNEP 2012; Umicore 2017; Commonwealth of Australia 2020; ISO 2017).

Procurement guidelines can have an impact on sustainability programmes at the sector level because they define requirements that customers must place on their suppliers. This means that procurement guidelines could also benefit from harmonisation with sector-specific standards. Otherwise, they add to the multitude of already existing standards and partially overlapping guidelines.

7.2.5 Resource efficiency

It is imperative for developing the mobility Roadmap to increase efforts for ensuring resource efficiency. *Resource efficiency* can be defined as humanity's ability to further expand the use of ecosystem services (i.e. services derived from resources), while reducing the actual amount of resources deployed (resource decoupling) and the associated environmental impacts (impact decoupling) (UNEP 2017). *Decoupling* describes a situation where resource use or environmental impact does not continue to increase at the same or a similar rate as economic growth. By decoupling resources and environmental impacts, it can either mean that they grow at a slower rate than the economic activity (relative decoupling) or that they decline with an increasing economic activity (absolute decoupling). In the following Figure 25, the different decoupling aspects are visualised.

Decoupling of both resource use and environmental impact from economic activity is called 'double decoupling'. The environmental benefits from increasing resource efficiency are not only related to reduced environmental impacts from mining but also impacts from resource consumption in general, like waste disposal or GHG emissions. Nevertheless, resource efficiency is not only an essential step to reduce environmental impact; it can also generate economic advantages by supporting companies and countries to withstand price volatility or promoting cost-saving innovations. In addition, resource security can be increased (Ekins and Hughes 2017).

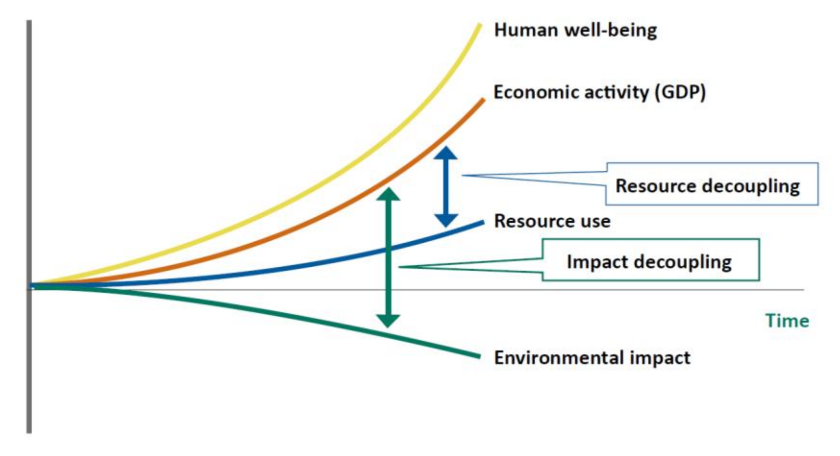

Figure 25: Decoupling of resource use and environmental impacts from GDP growth (UNEP 2011)

Resource efficiency can be increased by several measures: (a) increasing production efficiency with reduced raw material input, (b) reducing waste and losses along the supply chain, (c) recycling or reusing waste, and (d) modifying consumer behaviour and consumption patterns. The first three targets are usually referred to as the "3R" – reduce, reuse, recycle (Ekins and Hughes 2017; van den Berg et al. 2016).

For the mobility sector, instituting resource efficiency is key for successful transformation. In addition to reducing the amount of raw materials in battery cell production, consumption patterns need to change to make the transition achievable and affordable. However, policies often fail to include consumption patterns and consumer habits and rather focus on technological innovations (Ekins and Hughes 2017; van den Berg et al. 2016). This aspect was the reason for an open letter from 60 NGOS to the World Bank criticising the climate-smart initiative (see chapter 4.3.17). The fear is that the climate-smart mining initiative will further expand mining activities on top of the already growing demand, thus increasing environmental and social impacts. The initiative also calls for further strengthening of responsible mineral sourcing and rethinking of consumption and transport behaviour (Earthworks 2019).

7.2.6 Strengthen Recycling

The broad aim of circular economy is to reduce the negative impacts of primary raw material sourcing and the dependency of raw material imports. Recycling capacities for end-of-life Li-ion batteries need to be increased, as it is already becoming apparent that the recycling capacities will no longer be sufficient to meet market demands - even before the large return flow of end-of-life Li-ion batteries arrives. As recycling of lithium-ion batteries from the mobility sector is a comparatively young technology, improvements of recycling processes are to be expected, must be significantly scaled up and must be further supported financially with research funds e.g. from the European Union or within the Member States. This includes, on the one hand, a more efficient recycling process itself, which requires further technological development and research. But on the other hand, the entire process of collecting end-of-life batteries, as well as transport and storage, must also be considered.

Also, standards and regulations for recycling need be developed and considered. Recent research in this RE-SOURCING project identified that there are no international standards for recycling Li-ion batteries. However, the EU has several regulations in place that mention recyclers. The Battery Directive, which is essential for battery recycling, is currently under review, with a new proposal containing detailed and ambitious targets of revisions recently submitted by the European

Commission (see chapter 4.2.5). The EU's ELV Directive is also relevant for waste management of LIBs from passenger cars.

Recycling can be supported by setting guidelines and standards already for the design phase of a product (design for recycling). As well, possibilities to standardise batteries should be investigated, along with digitisation concepts to provide information about the battery cell structure and its construction.

An international approach to recycling Li-ion batteries is essential for several reasons: the high risk of fire and explosion of used or damaged Li-ion batteries; the valuable resources contained in batteries; sustainability advantages of secondary materials; and the fact that cars are often exported to other countries and continents, allowing these materials to leave the EU market.

In concrete terms, an approach of mandatory recycling content quota can be mentioned here (similar to the obligations in the plastics sector). However, shares must be flanked by further measures such as raw material quotas and take back systems (e.g. deposit). Recycling can be encouraged by **mandatory recycling content quotas**, which can in turn create a market for secondary resources. Prices for recycled materials compete against primary raw material prices. Often, primary materials are cheaper, making recycling economically unattractive. Introducing a mandatory recycled content can stimulate the recycling sector by artificially creating a rare good that will have a high demand and low supply.

In a growing market like the Li-ion battery market, relatively low volumes of end-of-life products are available for recycling. Accordingly, costs for battery recycling are high, as there are no economies of scale. In the normal market, this leads to high prices for the secondary raw materials and low demand compared to primary materials. In the worst-case scenario, no recycling takes place at all or the materials are downcycled since high quality recycling is economically not viable.

Introducing mandatory recycling content rates in new batteries could shift the situation. Companies producing goods would then be required to obtain secondary raw materials. As there would then be a limited amount of recycled materials available but a high demand, the prices would increase. Then recycling companies would be compensated for their efforts and would not directly compete with cheaper primary raw materials. In a more mature market even without recycled content quotas secondary materials might become more competitive compared to primary materials.

Moreover, a recycling infrastructure needs to be built which is significantly easier when investment security is guaranteed by creating a market for secondary materials. Profits from selling secondary materials would enable recyclers to maintain and build capacities for a growing volume of end-of-life products in a growing market (e.g. Li-ion battery market).

8 Conclusion & Next Steps

This report reviews and analyses the challenges for transforming the mobility sector, including the environmental and social impacts. The chapters presenting the Vision and remaining issues have indicated where the RE-SOURCING project needs to further focus in developing the Roadmap. Even though three value chain steps were selected for assessment in the project, all production steps along the value chain must be sustainably and responsibly carried out. This requires a transparent and holistic international framework for every step in the automotive or certainly the traction battery supply chain.

During the research and work on the State of Play document and Roadmap concept, it became clear that, in addition to the selected three supply-chain steps (mining, cell production, recycling), the automotive industry will play an essential role in elaborating the recommendations resulting from the project. Original equipment manufacturers (OEMs) have strong connections with battery cell producers and car manufacturers that are themselves trying to secure the raw material supply by becoming shareholders of mining companies or mining sites. Therefore, recommendations in the Roadmap will also focus on car manufacturers, as they are key players and have strong market power.

Existing standards and initiatives for the mining sector (chapter 4.3) are very comprehensive but do not contain measures for all challenges in the sector. The different challenges based on location and raw material make it difficult for one standard to cover all areas. Therefore, mutual recognition and an overarching framework must be developed and promoted. No further mining standards and initiatives should be added to the jungle of those that already exist. Furthermore, the traceability of raw materials through the supply chains needs to be fostered.

Overall, it should be highlighted that an increase in resource efficiency and decoupling the resource use from economic growth is essential to preserve natural capital and achieve climate goals.

The Mobility Roadmap of the RE-SOURCING project will be developed based on the results of this report in cooperation with stakeholders of the mobility supply chain. The aim of the Roadmap 2050 is to provide guidance for companies and policy makers on how to address the identified sustainability challenges in the mobility sector, with the focus on Li-ion batteries.

In parallel to developing the Roadmap, Flagship Cases (good practice examples) with transferrable approaches will be identified. A selection will be presented within a peer-learning process transferred to other actors (beginning 2022). The associated good practice guidance document will be developed after the Flagship Lab and the content will be integrated in the final Roadmap in summer 2022.

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Annex: Narrative Analysis on responsible sourcing

In this annex an extract is provided of the narrative analysis on responsible sourcing, taken in part from the report *State of Play and Roadmap Concepts: Renewable Energy Sector. RE-SOURCING Deliverable 4.1* by Marie-Theres Kuegerl and Michael Tost (Kügerl 2021).

Table 9 lists the selected narratives (i.e. terms) related to responsible sourcing.

Table 9: Selection of narratives for responsible sourcing (see Kügerl 2021)

No	Responsible Sourcing		Responsible Sourcing
1	"due diligence" procurement	23	"responsible mining"
2	“human rights” procurement	24	sustainability mining
3	“responsible procurement” raw materials	25	"responsible sourcing"
4	sustainable procurement	26	"responsible sourcing" minerals
5	“green procurement” raw materials	27	"responsible sourcing" raw materials
6	"environmental impact" procurement	28	"responsible sourcing" blockchain
7	"carbon footprint" procurement	29	sustainable "raw materials"
8	"local procurement" minerals	30	certification "raw materials"
9	"green energy" mining	31	"supply chain" transparency
10	"artisanal and small-scale mining"	32	responsible "supply chain"
11	corruption mining	33	"London Metal Exchange" responsible sourcing
12	"free prior informed consent" mining	34	"Responsible Minerals Initiative"
13	"grievance mechanism" mining	35	"Towards Sustainable Mining"
14	"health and safety" mining	36	EITI
15	"social impact" mining	37	ICMM principles
16	mining "living wage"	38	IFC guidelines mining
17	"value creation" mining	39	ILO standards mining
18	ESG mining	40	IRMA standard
19	"biodiversity loss" mining	41	OECD "responsible mineral supply chain"
20	mining "toxic chemicals"	42	World Bank "climate-smart mining"
21	mining reclamation	43	OECD procurement guidelines

22	sustainable mining		

The narrative analysis for the RE-SOURCING project was meant as a control mechanism, to assess whether the selected topics are relevant for the responsible sourcing and renewable energy agenda are actually resonating with the global media. Table 10 shows the results of the analysis.

A major result of the narrative analysis indicated that the topics and challenges for the responsible sourcing and renewable energy agenda chosen by the RE-SOURCING team are quite well reflected in the discourse of global media. A large number of the narratives assessed were categorised as timeless narratives (highlighted in green). Few were transformational (orange) and some were on the border between transient and timeless (yellow) or tribal and transformational (blue). The remaining narratives were found transient. The result is very positive, as an unusually high number of the narratives chosen classified as timeless (32.5% for responsible sourcing and 35% for renewable energies). This supports the proposition that the topic areas that were chosen to address in this report accurately reflect the issues that are currently discussed in the media and global public discussions in general.

The remaining narratives were not in the public eye at the time of the analysis, which means for the RE-SOURCING project that these areas need further engagement within the roadmap, but also by policy makers and organisations promoting responsible practices. The 34 narratives that were found to be transient include *"human rights procurement"* and *"social impact mining" for responsible sourcing*, and *"biodiversity loss renewables"*, or *"life cycle assessment solar panels" and wind turbines for renewable energy* (for detailed results, please see Table 10 unmarked terms). The measured lack of engagement means these narratives were not attracting attention nor were they strong narratives. The absence of relevance may mean that for the narratives related to achieving sustainability and responsibility in the supply chains, some issues pertaining to these areas may require further investment by the RE-SOURCING project.

Responsible Sourcing: Starting with the topic of responsible sourcing and looking directly at the narrative "responsible sourcing", the narrative generated a very positive response. The most intense emotions associated with it were joy, contentment, satisfaction, and fulfilment. Other, weaker emotional responses were hope, encouragement, and expectation. These emotions are shown in Figure 22 A. Highlighted in green are positive emotions, blue are emotions with a clear tonality, such as expectation or surprise, red indicates negative emotions. The intensity of emotions is indicated by the intensity of the colours.

The key players driving the narrative of responsible sourcing were the OECD and the London Bullion Market Association (LBMA). Furthermore, Philips, the Human Rights Watch and Trafigura were important supporters of the narrative. Considering the content, this narrative was mainly driven by Walmart and publications on their corporate website. LBMA and Trafigura, also with company-owned publications, were found to have considerably less content power. The results indicated this topic to be relevant for European and American companies alike, as well as global organisations invested in this narrative.

To compare the results and assess what the more commonly used syntax is, sustainable procurement was chosen. The narrative “sustainable procurement” generated the same emotional response as “responsible sourcing”. However, the emotional intensity was found to not be as strong and this is considered a measure for real engagement. The key players driving this narrative were the World Economic Forum (WEF) and UN Global Compact, both can be considered very powerful global drivers, apart from mainly governmental departments. Regarding the content, it appeared there is a global interest in this topic. In addition to the organisations mentioned above, two regions seemed to influence this narrative - Scotland and Canada (the City of Vancouver). A comparison with the narrative “responsible supply chain” again shows similar positive reactions, but “responsible sourcing” remains the strongest narrative.

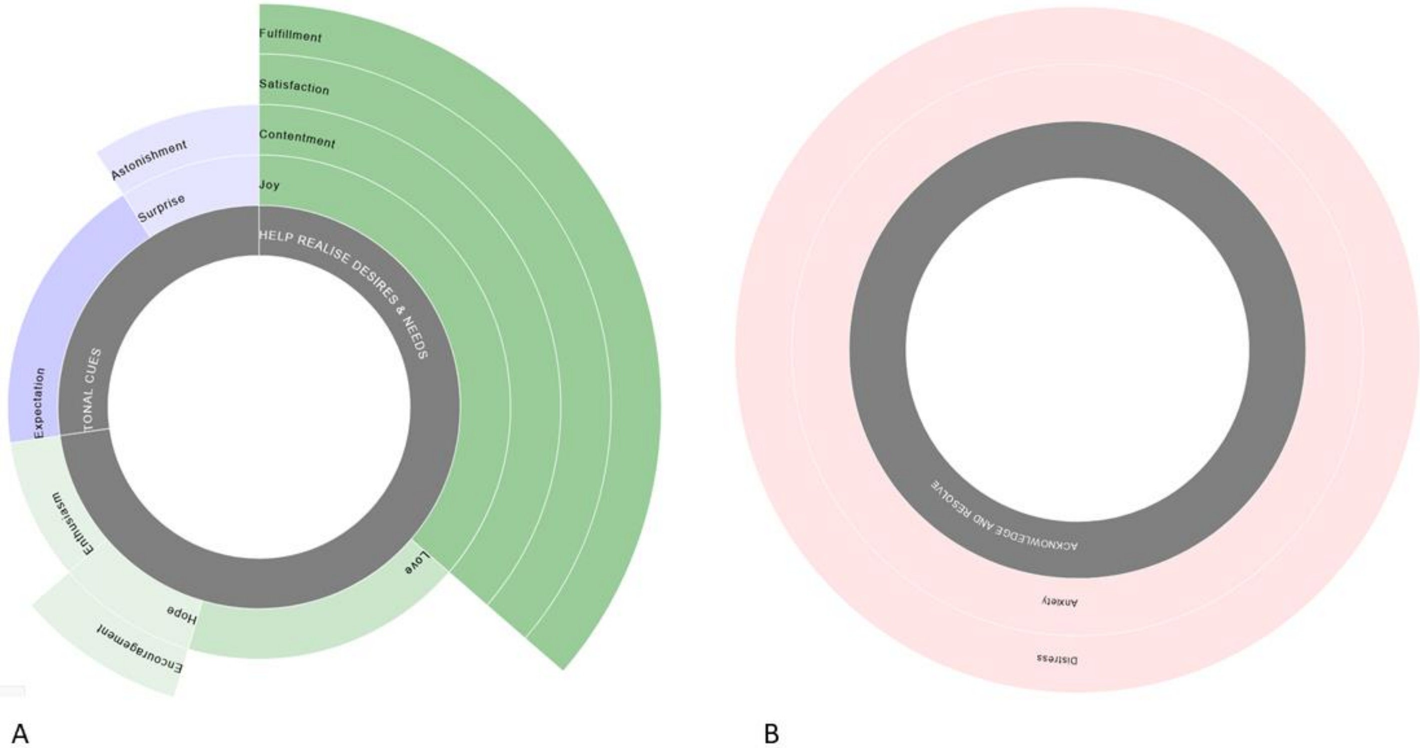

Figure 26: Generated emotions related to (A) "responsible sourcing", (B) “sustainable raw materials” (Kügerl 2021)

Sustainability: Looking at some narratives with the terms “sustainability” and “sustainable”, the first thing that was noticeable is that sustainability mining, sustainable mining, and sustainable raw materials were connected to rather negative or neutral (mainly expectation or surprise) emotions. Interestingly, the narrative “sustainability mining” was mainly driven by crypto mining content and stakeholders. It is therefore not relevant for our study. However, “sustainable mining” was highly relevant and included drivers such as the World Bank, ICMM, the Responsible Mining Foundation, etc. What stood out is that by far the strongest content is the Philippines' commitment to the TSM initiative and the narrative was characterised by expectation. Apart from the Philippines, mainly Canada was the dominant country. “Sustainable raw materials” was fully associated with negative emotions (Figure 22 B).

The narrative “sustainable raw materials” is not characterised by a lot of media voices and content, but the strongest drivers were journalistic articles and the EIT RawMaterials. On the content side, the company BioMar a diet producer for fish and shrimp dominated the subject, which is of course not relevant to this project.” (Kügerl 2021)

In the following table the results of the clustering in timeless, transformational, transient and tribal are provided.

Table 10: Results of narrative analysis, green – timeless, orange – transformational, yellow – between transient and timeless, blue - between tribal and transformational, grey – tribal (Kügerl 2021)

No	Responsible Sourcing	No	Responsible Sourcing
1	"due diligence" procurement	23	"responsible mining"
2	“human rights” procurement	24	sustainability mining
3	“responsible procurement” raw materials	25	"responsible sourcing"
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16	mining "living wage"	38	IFC guidelines mining
17	"value creation" mining	39	ILO standards mining
18	ESG mining	40	IRMA standard
19	"biodiversity loss" mining	41	OECD "responsible mineral supply chain"
20	mining "toxic chemicals"	42	World Bank "climate-smart mining"
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