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BGR

Raw materials for electric mobility

A development perspective

Raw materials for electric mobility

A development perspective

Foreword

The international community is facing an enormous challenge: climate change is threatening our resource base and our livelihoods. We need to drastically reduce greenhouse gas emissions if we are to achieve the goal set out in the Paris Agreement on climate change and keep global temperature rises to 1.5°C, thus leaving future generations a planet fit for them to live on. This calls for a massive shift in the energy and traffic sectors, to embrace low-emission alternatives.

The carbon dioxide emissions generated by the traffic and transport sector are one of the main drivers of climate change. In 2016, this sector was responsible for about one quarter (23%) of all energy-related CO_2 emissions, and this figure is rising steadily. In Germany as elsewhere, the transport sector is the third largest source of carbon dioxide emissions. And that is why we need a global mobility shift. We need a transformation of our mobility. We need to move towards active, public, shared mobility and we need to embrace sustainable technologies such as electric mobility – in Germany and around the world.

That brings us to the preconditions for electric mobility, to ways of storing electric power and to batteries, and to the raw materials we need to manufacture them.
To manufacture the lithium-ion batteries that are commonly used today, we need lithium, copper, cobalt and other minerals. And that moves the spotlight to the supply chain. How can mining be made sustainable and equitable, and how can we step up recycling to embrace the entire life cycle of a battery, from its design to use, collection and disposal?

The raw materials mentioned above often come from developing countries or emerging economies, where resource wealth does not always reduce poverty. There are some encouraging examples in the countries of the global South however, where revenue from the extractive sector has been used to improve living conditions in the long term.

Yet the production of raw materials entails a great many social and environmental risks and challenges. Children often work in artisanal and small-scale mining. It is estimated that about 1 million children work in mining around the world. In some places, violent conflicts are financed with money generated by the extractive industry. In some regions, forests are lost so that land can be mined. Deforestation in turn reduces biodiversity and limits the availability of ecosystem services, such as water quality. The vital resources that are the basis of the livelihoods of the local communities are also jeopardised.

This means that the materials we need for the global mobility shift must be mined in compliance with environmental and social standards. Our future in Europe is closely intertwined with the future of the resource-producing countries. That is why the German Federal Ministry for Economic Cooperation and Development (BMZ) has long supported partner countries in the sustainable development of their extractive sector. We use projects and political initiatives to foster the development of responsible natural resource supply chains to ensure that the population and the environment can benefit from the extractive industries.

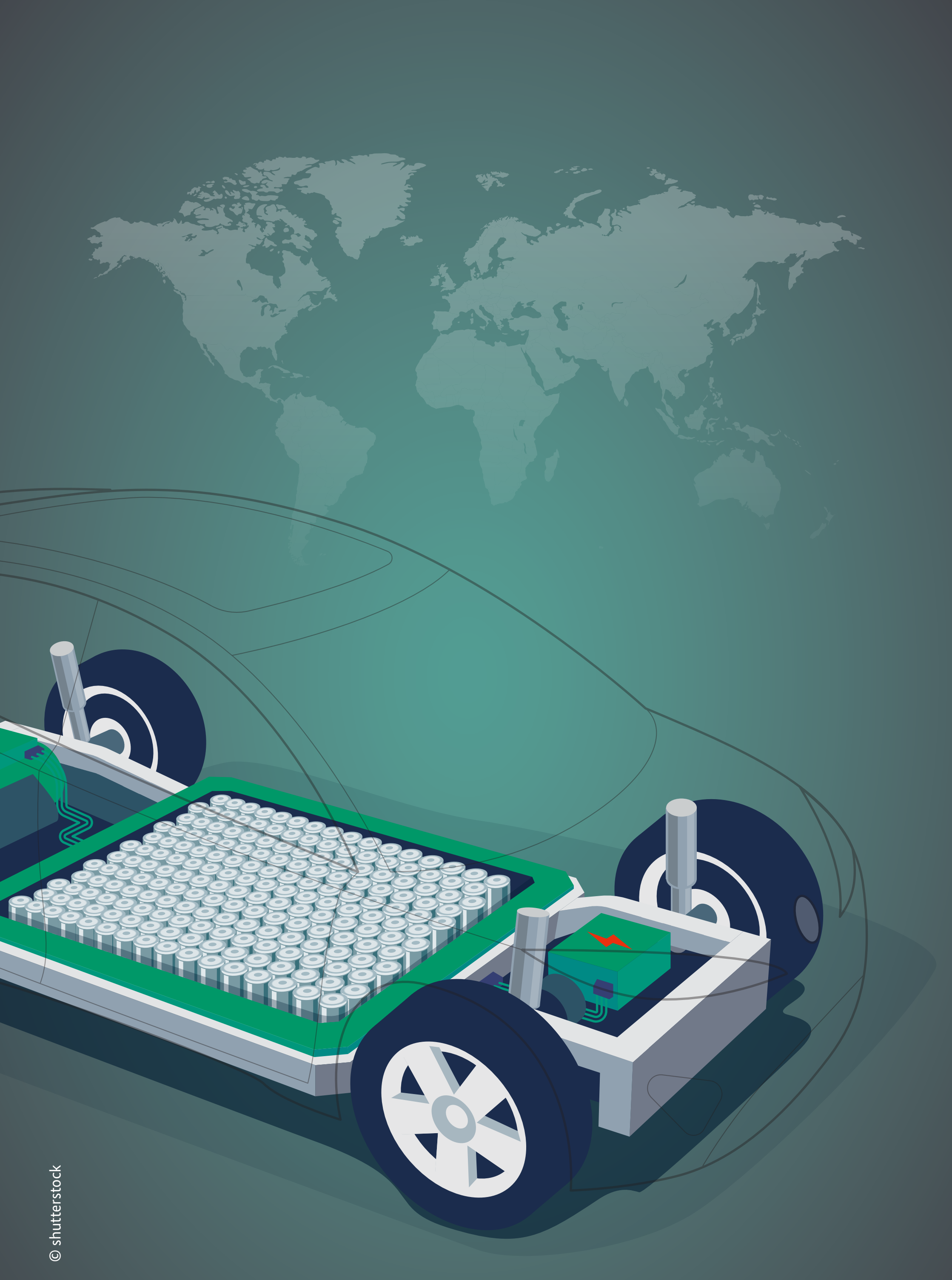
This publication is designed to give you an overview of the natural resources that are needed in electric mobility, and how German development cooperation helps foster the responsible mining of these resources.

I hope you enjoy it.

Dr Heike Henn

Director for climate and energy;
sustainable urban development; environment

Commissioner for climate policy and climate financing
Federal Ministry for Economic Cooperation and Development



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Abbreviations

ASM	Artisanal and small-scale mining
BEV	battery electric vehicle
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development)
CO_2	Carbon dioxide
CTC	Certified Trading Chains
DERA	Deutsche Rohstoffagentur (German Mineral Resources Agency)
EITI	Extractive Industries Transparency Initiative
EPRM	European Partnership for Responsible Minerals
EU	European Union
EUR	Euro
GDP	Gross domestic product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
ICGLR	International Conference on the Great Lakes Region
LIB	Lithium-ion battery
LFP	Lithium iron phosphate battery
LME	London Metal Exchange
LSM	Large-scale mining

MinSus	Regional Cooperation for the Sustainable Management of Mining Resources in Andean Countries
MWh	Megawatt-hour
NMC	Nickel-manganese-cobalt
OECD	Organisation for Economic Co-operation and Development
RINR	Regional Initiative against the Illegal Exploitation of Natural Resources
SDGs	Sustainable Development Goals
SHFE	Shanghai Futures Exchange
t	metric ton
TC	Technical cooperation
USD	United States dollar

Future mobility

Mobility is the essential prerequisite for economic growth, prosperity and quality of life. In many countries, however, cities are facing total gridlock with traffic jams, air pollution, climate-damaging emissions and massive adverse impacts on human and economic health. Globally, the traffic and transport sector is responsible for about one quarter of energy-related greenhouse gas emissions [1]. This could rise to 70% by 2050 [2].

The global challenge is to drastically reduce emissions in the sector while meeting increasing demand for mobility. This will call for a global transformation in the traffic and transport sector that builds on two pillars: a mobility shift and a transformation in the energy used in the sector.

The mobility shift presupposes above all a change in demand for mobility and a behavioural change. It is part of a process of societal transformation. By preventing traffic (e.g. through integrated urban development and more remote working) and encouraging a shift to different means of transport (developing local public transport and active mobility, along with multimodal transport)[1] we can reduce the total energy consumption of the traffic and transport sector.

Transforming the energy used in the sector, by contrast, is a technical challenge, which requires more renewable energy to be used in the sector. Electric mobility has a key role to play, since it could in future be powered solely by renewables. Electric mobility would make it possible to dispense entirely with fossil fuels. Alongside the efficient use of electric engine power, it also creates the option of locally emission-free mobility. For the essential decarbonisation of the traffic and transport sector, electric mobility will be used increasingly in a variety of forms (trains, electric buses, electric bikes, electric rickshaws, electric cars, etc.).

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1 Strategy to make transport better suited to cities. Multimodal transport means using a variety of different means of transport for a journey.
Find out more at *https://www.unescap.org/sites/default/d8files/event-documents/03MultimodalTransportationConceptAndFramework.pd* .

Without natural resources there can be no electric mobility. Because electric mobility driven by lithium-ion batteries needs more natural resources than is required for vehicles with internal combustion engines, electric mobility depends on the extractive industries. This presents new challenges for global supply chains.

Resources such as lithium, cobalt, nickel, graphite, aluminium, tin, manganese and copper are used, for instance, to produce lithium-ion batteries that power electric mobility. The extraction of these resources brings with it a number of social and environmental risks. After batteries have been used in vehicles, the question of the 'second-life applications' of batteries arises. They need to be recycled or disposed of in an environmentally acceptable manner. To reduce the resource intensity, and channel important secondary resources back into production, the entire life cycle must in future be accorded greater attention from design to use, collection and disposal.

This publication explains what natural resources are used to manufacture lithium-ion batteries, and in which countries under which conditions they are produced and processed. It also looks at the opportunities and risks posed by the robust growth in electric mobility to the extractive sector in developing countries and emerging economies.

THE STRUCTURE OF BATTERY SYSTEMS

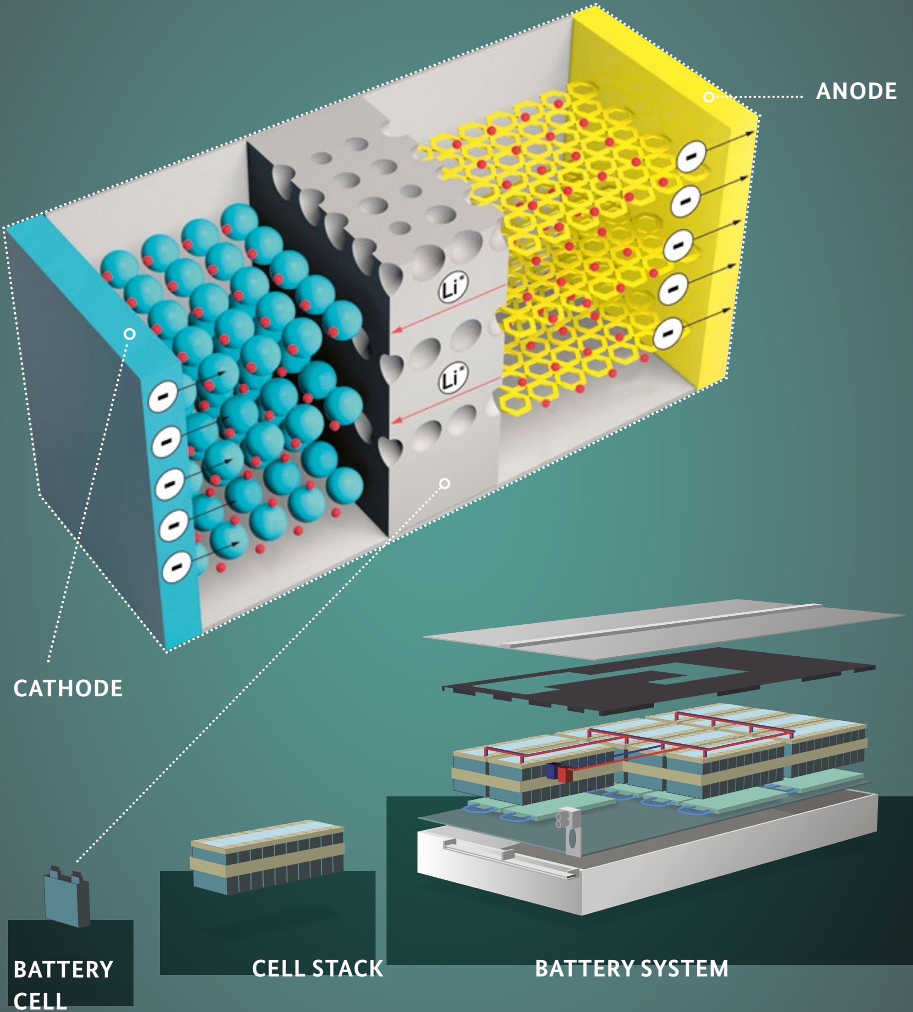


Fig. 1: Modern batteries are based on the use of minerals such as lithium, cobalt, nickel, manganese and graphite. Two types of lithium-ion batteries have made the running in electric mobility to date. The main difference is in the materials used in the cathode: nickel-cobalt-aluminium (NCA) or nickel-manganese-cobalt (NMC).

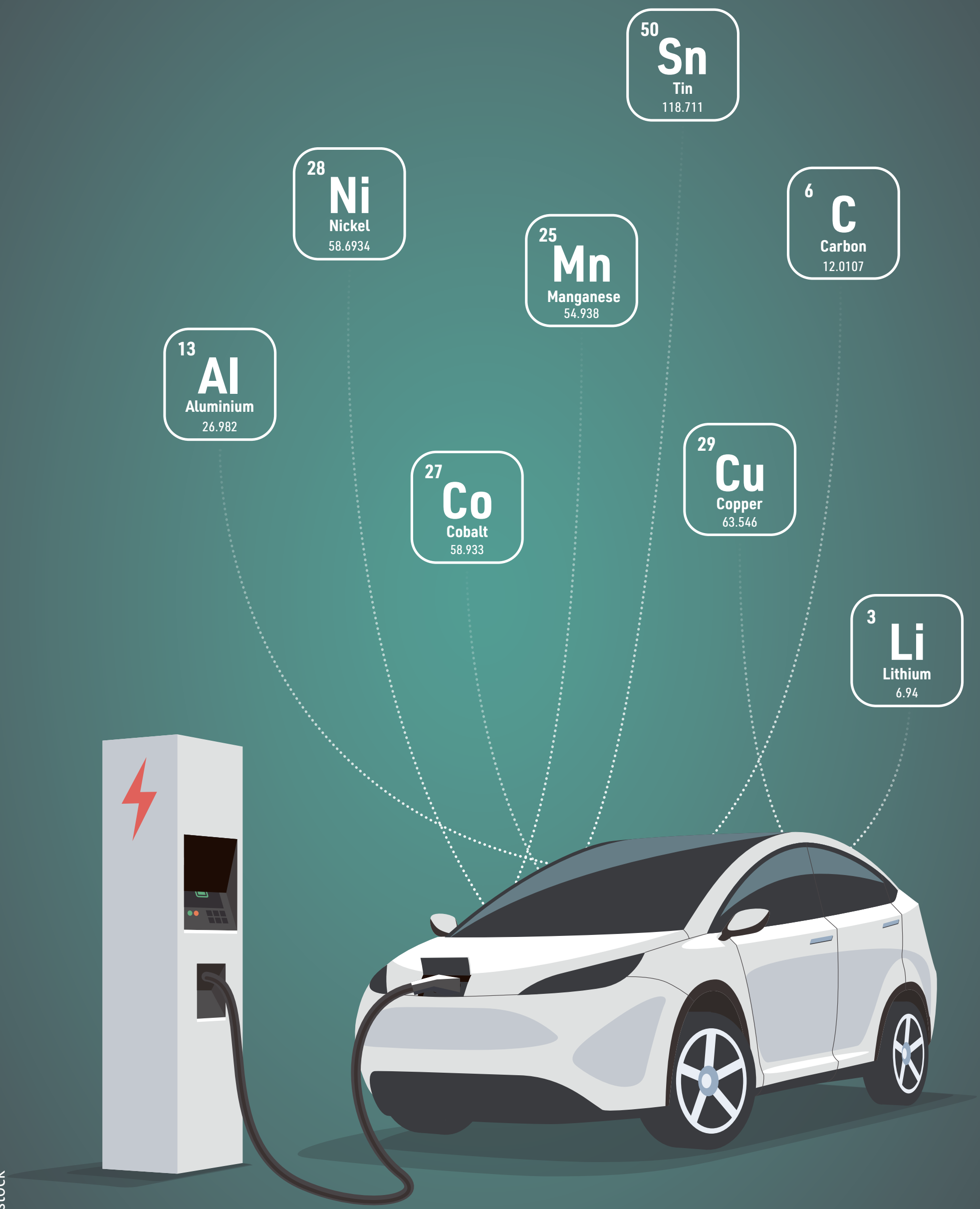
How is a lithium-ion battery for a battery electric vehicle (BEV) built?

Lithium-ion batteries[2] are rechargeable electrochemical energy storage devices. The life span of a battery is stated in terms of charge cycles. Most battery types consist of a number of cells in order to increase the battery output. One cell consists of two electrodes: the negative electrode (anode) and the positive electrode (cathode). The electrodes consist of a collector (e.g. coated copper foil) and an active material. The active material used in lithium-ion batteries varies, with different combinations found. A graphite anode and a nickel-manganese-cobalt (NMC) cathode is the most widely used combination.

The cathode of an NMC111 battery[3] (30 kWh output) that is often fitted in customary mid-range private cars contains 11 kilograms manganese, 4.5 kilograms lithium, 12 kilograms cobalt and 12 kilograms nickel [3].

2 We will use the term 'battery' for short.

3 An NMC111 cathode contains nickel, manganese and cobalt in a ratio of ~1:1:1, whereas an NMC811 cathode contains these elements in a ratio of ~8:1:1.


50 Sn Tin 118.711
28 Ni Nickel 58.6934
25 Mn Manganese 54.938
6 C Carbon 12.0107
13 Al Aluminium 26.982
27 Co Cobalt 58.933
29 Cu Copper 63.546
3 Li Lithium 6.94

Future demand for raw materials

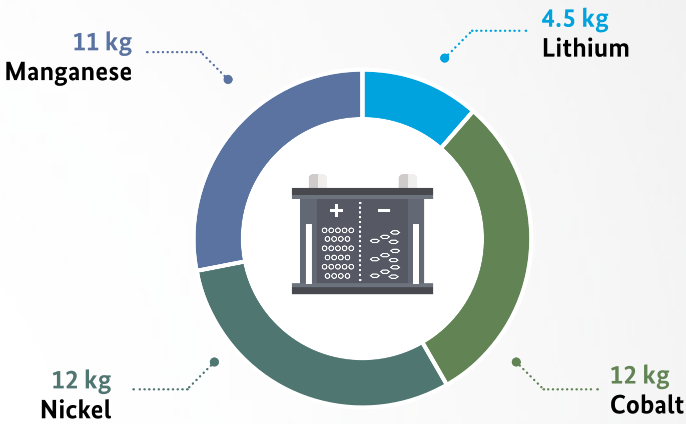


Fig. 2: Raw materials used to produce the cathode for an NMC111 battery with a capacity of 30 kWh.

The demand for electric mobility is rising rapidly. In 2019, global sales of electric vehicles increased to over 2.1 million, accounting for 2.6% of worldwide car sales. In Germany, the Federal Government has set the target of getting between 7 and 10 million electric vehicles onto the road by 2030. It has introduced financial incentives to help achieve the goal as well as investing in the charging infrastructure [4]. At the end of 2020 some 7.2 million electric vehicles were on the road worldwide. That is equivalent to about 1% of all cars and marked a 40% increase over 2019 [5]. Climate targets mean we can expect the number of electric cars on the roads to continue to rise strongly. More electric cars mean that more natural resources are needed to manufacture them. It is difficult to put a figure on future demand for these battery raw materials, however, since it depends on battery size, the type of cathode used and technical innovation. The German Mineral Resources Agency (DERA) at the Federal Institute for Geosciences and Natural Resources (BGR) estimates that the demand for cobalt could more than double, from 110,000 t in 2017 to as much as 225,000 t in 2025, while demand for lithium could increase by a factor of six, from 35,000 t in 2015 to 224,000 t in 2025 [6] [7].

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Fig. 3: When the local population also benefits from the extraction of natural resources, the potential of the sector can be better used and sustainable development achieved as laid out in the 2030 Agenda.

Natural resources and sustainable development

In many developing countries and emerging economies, the extractive industries can contribute to sustainable development. The extractive sector generates revenues for the state and creates new jobs. Yet many resource-rich countries are still benefiting too little. How can they better harness the potential offered by the natural resources sector and achieve sustainable development as set out in the 2030 Agenda?

They will only manage to do so if the local population also benefits from the extraction of natural resources – the burden and benefits of extraction should be evenly spread. This can be achieved by ensuring value is added locally, guaranteeing transparency and fair wages. In addition, extraction activities must be environmentally sound and climate-appropriate. The extractive sector must be steered such that human rights violations and adverse impacts on the environment, peace and security are prevented. These are questions for mining supervisory authorities and the legal framework, which also depend on the prevailing local conditions.

If it is properly managed, the extractive sector can help achieve several of the Sustainable Development Goals (SDGs):

The extractive sector can help end poverty (SDG 1).

Many natural resources are needed to manufacture modern, sustainable technologies (e.g. renewable energy technology and electric cars). This helps achieve SDG 7 – access to affordable, reliable, sustainable modern energy for all.

Stepping up local value added for sustainable economic growth and decent work for all (SDG 8).

Mining can help drive economic development by promoting new infrastructure for traffic, transport, communication, water and energy (SDG 9).

Creating sustainable and fair supply chains for natural resources (SDG 12).

Use of renewable energy in mining, also to supply surrounding communities (SDG 13).

Mobilising revenue that can be used for sustainable development in producer countries (SDG 17).

The downside is, however, that there are still inherent social and environmental risks to mining, especially in developing countries and emerging economies:

Miners face health risks if occupational health and safety measures are not respected (SDG 3).

In artisanal and small-scale mining, child labour is sometimes found. Since these children are not attending school, this is an obstacle to achieving education for all (SDG 4).

Structural gender inequality in mining impairs gender equality (SDG 5).

Mining entails significant risks for the protection of land-based ecosystems (SDG 15).

Corruption and the financing of conflicts from revenues generated by mining and natural resources jeopardise the goal of achieving peace, justice and strong institutions (SDG 16).

Fig. 4: Skyline of Santiago de Chile with modern office buildings in the Las Condes financial district.

In spite of all the risks and challenges, resource wealth can have a very positive impact on the economic development of countries. Botswana, for instance, was one of the poorest countries in the world, but has been able to develop its economy using revenue from the mining of diamonds and other natural resources. Revenue has been used, for instance, to massively expand the country's education and health systems. The extractive sector has also enabled Chile to move from a developing country to an OECD state.

Fig. 5: The new business district in Bagorone, Botswana.

The extractive sector is highly diverse in terms of the size of mines and the level of mechanisation used. In general, a distinction is made between **artisanal and small-scale mining** (ASM) and **large-scale mining** (LSM).

The level of mechanisation in **artisanal and small-scale mining** is often very low. Sometimes there is no mechanisation at all and miners work with very rudimentary tools (pickaxes, hammers and pans). The World Bank estimates that about 40 million people worldwide work in artisanal and small-scale mining [8]. The resources mined in this way are numerous: construction materials, precious stones, diamonds and cobalt, to give a few examples. The main focus is on mining gold, however. World-wide 15-20 million people are involved, albeit frequently illegally or informally. The artisanal and small-scale mining sector is thus highly relevant for development, and entails risks and challenges for development cooperation – but it also offers potential.

Large-scale mining, by contrast, is highly mechanised and conducted by private companies, some of them with multinational operations. Unlike artisanal and small-scale mining, large-scale mining employs relatively few people, but it is an essential economic factor in many regions. In many countries, especially in Africa, the extractive sector also accounts for a significant percentage of GDP and the tax revenue generated finances a large proportion of the budgets of many governments. On the other hand there are risks of corruption and tax avoidance.

Fig. 6: Small-scale mining in West Africa's Kono Region.

Fig. 7: The Centinela industrial copper mine in Chile's Antofagasta Region.

Fig. 8: In many parts of Africa, as here in Kono in West Africa, small-scale mining is an important economic mainstay of the local population.

Overview of development cooperation activities in the extractive sector

Sectoral activities

On behalf of

Federal Ministry for Economic Cooperation and Development

Extractives and development sector programme

Implemented by

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

BGR

The extractives and development sector programme is being implemented on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ) by BGR and GIZ. Policy advisory services are at the heart of the project. GIZ and BGR are together delivering advice involving both short-term enquiries on current issues and analysing trends in the international debate on a responsible extractive sector. The programme also works with projects in other countries and with partners in countries addressed by German development cooperation in order to develop new approaches that will make the extractive sector more sustainable.

CONNEX Support Unit

CONNEX Support Unit

The CONNEX Support Unit, which implements the G7 CONNEX Initiative and is attached to GIZ, supports developing countries and emerging economies globally in the negotiation of complex investment contracts. Fairly negotiated investment contracts in the extractive sector are an important basis for state revenue. Many developing countries rarely manage to ensure a fair share of revenues, because of the imbalance in terms of capacities and experience on the part of international investors on one side and governments on the other in the context of complex contractual negotiations.

Extractive Industries Transparency Initiative (EITI)

EITI is a global initiative designed to address the 'curse' of resource-rich countries by ensuring financial transparency and accountability. EITI was founded in 2002 and is now implemented in 55 countries (as at March 2021). Participating countries provide annual information about tax payments, licences, the volumes extracted and other important information relating to oil, gas and mining. EITI involves voluntary commitments on the part of governments and is jointly implemented in member states by state and civil society actors and by major corporations and investors (multi-stakeholder process).

Extractive Industries Transparency Initiative

European Partnership for Responsible Minerals (EPRM)

The EU Regulation laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas came into effect in 2017. As of 2021, importers must prove that their metal and mineral imports come from responsible sources. The EPRM is a development-policy measure to support the Regulation. It fosters innovative projects in artisanal and small-scale mining in producer countries and helps companies implement due diligence. It also strengthens dialogue, networking and a knowledge transfer between the actors in supply chains in the extractive sector.

European Partnership for Responsible Minerals

Bilateral/regional activities

Democratic Republic of the Congo: Bilateral projects for a responsible extractive sector

German development cooperation (BGR and GIZ) supports Congolese partners in developing the extractive sector as a driver of sustainable economic development in the country. It also fosters transparency and public participation in the extractive sector.

- BGR is cooperating with Congolese partners on measures to stem the financing of conflicts by extracting and selling natural resources and to improve the situation of those working in artisanal and small-scale mining. BGR supports the implementation of the Certified Trading Chains (CTC) system for responsible small-scale extraction of tin, tantalum, wolfram and gold. Preparations are underway to apply CTC in the cobalt sector.

- The GIZ project supports various public- and private-sector actors, helping to fully develop the potential of the mining sector in the Democratic Republic of the Congo. This includes improving training and employment and raising the level of professionalism.

Strengthening public management of the mining sector in Mozambique II

The technical cooperation project implemented by BGR in Mozambique is enhancing the technical expertise of the Ministry of Mineral Resources and Energy and its downstream authorities.

Support to the International Conference on the Great Lakes Region (ICGLR)

The Great Lakes Region embraces Angola, Burundi, Kenya, the Democratic Republic of the Congo, the Republic of the Congo, Rwanda, Zambia, Sudan, South Sudan, Tanzania, Uganda and the Central African Republic. The region is rich in mineral resources that are of great interest to the global economy. The illegal extraction of and trade in these resources are further aggravating local political conflicts. The programme, which is being implemented jointly by BGR and GIZ, aims to stem the trade in illegally extracted resources in the signatory states of the ICGLR.

- GIZ supports the Secretariat of the ICGLR with regional consultation processes relating to implementing the ICGLR Regional Initiative against the Illegal Exploitation of Natural Resources (RINR).

- The BGR module strengthens the capacities of national authorities. With the ICGLR Secretariat, BGR is developing a confirmation of origin for certain mineral resources (analytical fingerprint).

Regional Cooperation for the Sustainable Management of Mining Resources in Andean Countries (MinSus)

The programme, which is implemented by BGR and GIZ, fosters international standards to develop responsible mining practices that help advance the climate agenda at international level and to achieve the SDGs at local level. This is achieved by implementing pilot projects and sharing lessons learned among regional partners.

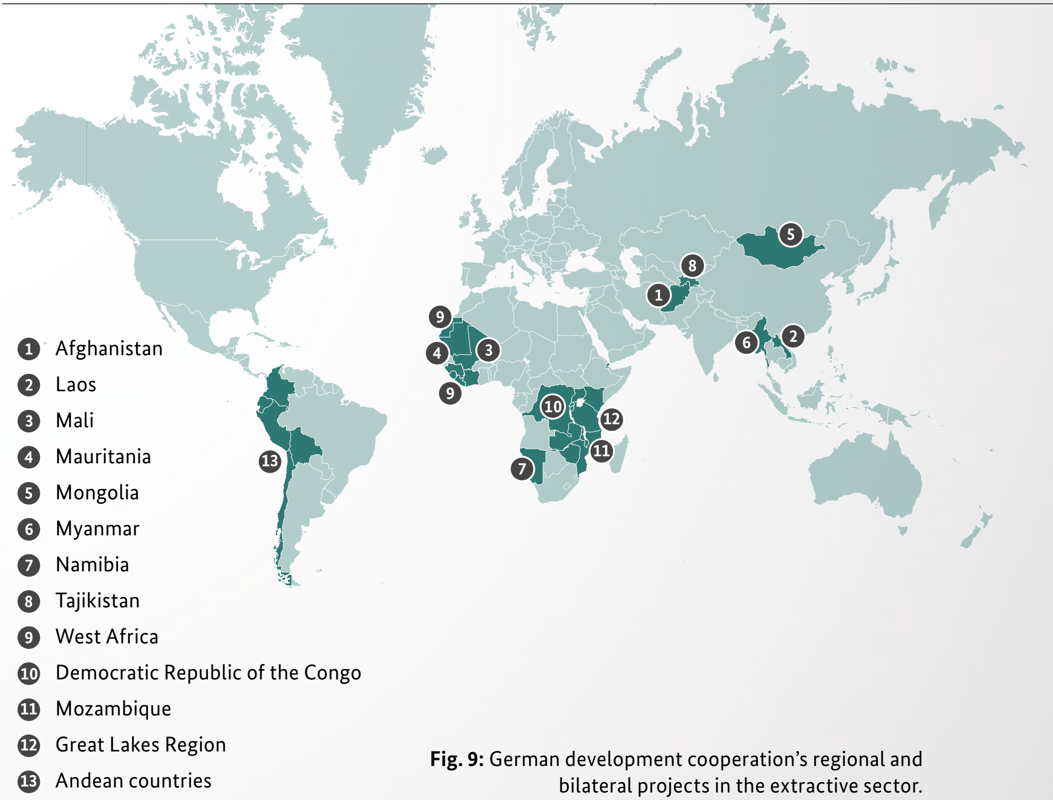


Fig. 9: German development cooperation's regional and bilateral projects in the extractive sector.

Natural resource supply chains

Natural resource supply chains in the manufacture of electric cars are often highly complex and global. A huge number of people and companies in different countries are involved before the consumer takes delivery of an electric vehicle. Within supply chains, we make a distinction between upstream and downstream. Upstream refers to the extraction of the natural resources, transport and processing in a refinery or other plant. Downstream refers to the supply chain in the manufacturing of the final product.

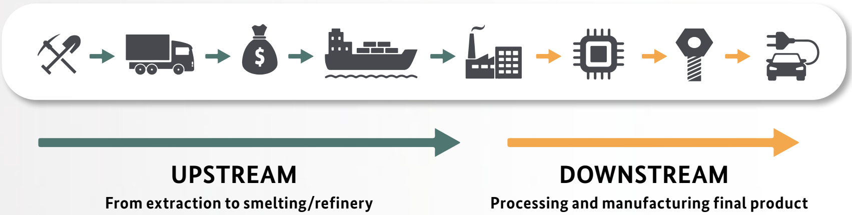


Fig. 10a: Explanation of upstream and downstream.

In artisanal and small-scale mining it can be difficult to trace upstream supply chains because so many producers and intermediaries can be involved.

Fig. 10b: Examples of supply chains in small-scale and large-scale mining.

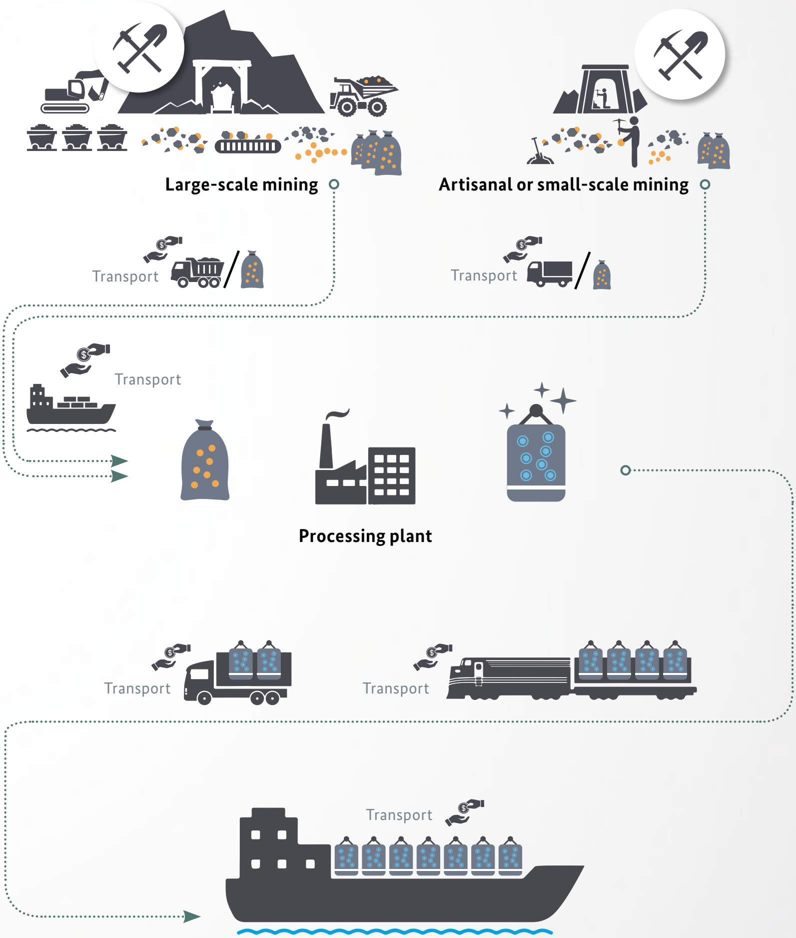


Fig. 11: Guinea is one of the major exporters of bauxite, an aluminium ore.

Aluminium & aluminium ore (bauxite)

Main producer countries [29]

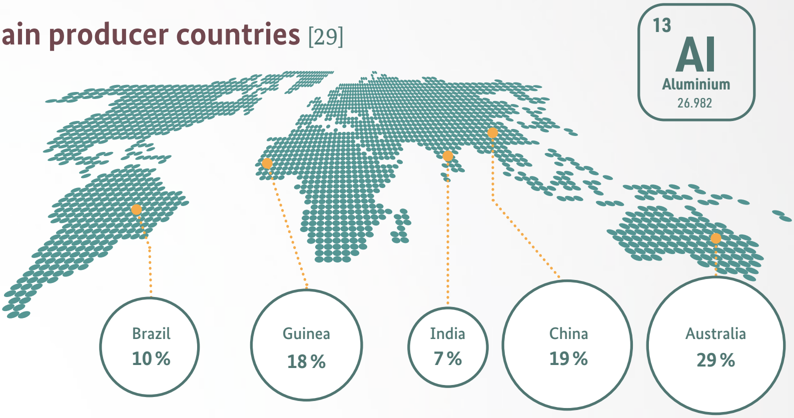


Fig. 12: Bauxite is mainly mined on an industrial scale. It is processed to produce aluminium oxide. This is then smelted to produce primary aluminium.

Supply chain

Bauxite is mined primarily on an industrial scale and the different stages in processing are closely interconnected. That makes it comparatively easy to trace the bauxite/aluminium supply chain. The main upstream actors are Australia, China and Guinea. Guinea and Australia are the world's main exporters of bauxite, and account for 50% and 20% respectively of exports (2018) [9].

In the midstream area, bauxite is processed to produce aluminium oxide, which is smelted to produce primary aluminium. Both processes generally take place in countries with low energy costs and good transport infrastructure. Most aluminium oxide and aluminium metal is produced in China, which produces 55% of the world's aluminium oxide and 56% of aluminium *(see Fig. 12 above and Fig. 13 on page 36)*. However, India, the United Arab Emirates, Canada and the Russian Federation are also important actors at this stage [10] [11]. Downstream, primary aluminium is used as a light metal and a component in alloys. In 2018, the USA was the main importer of non-alloyed aluminium (16% of global imports). Germany ranks among the top three countries in both the export and import of aluminium semi-finished products [12] [11] [13] [14] (2018).

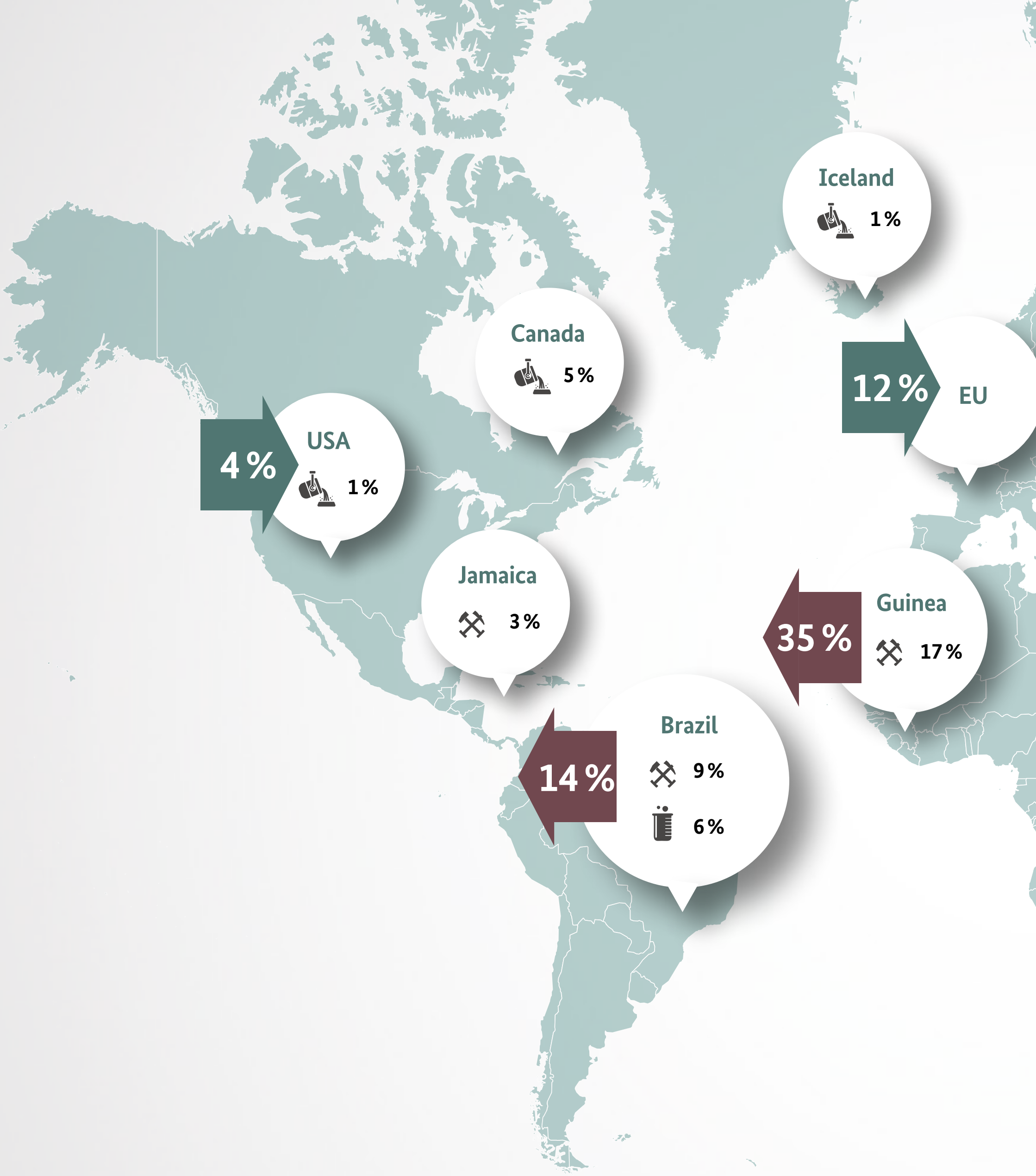
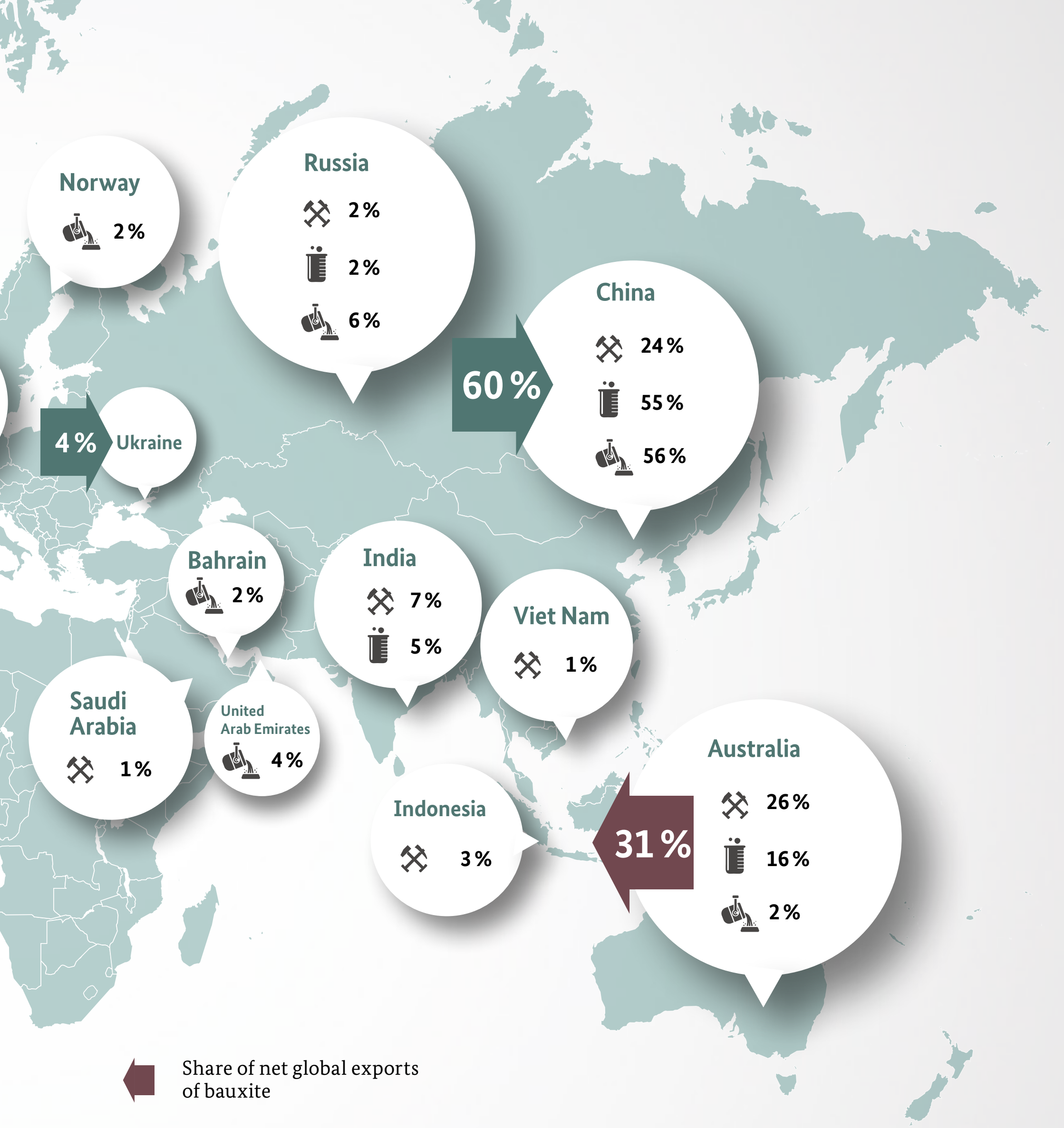


Fig. 13 Global trade and production of Bauxite, Alumina and Aluminium.



Share of net global exports of bauxite

Share of net global imports of bauxite

Share of global bauxite production

Share of global production of aluminium oxide

Share of global aluminium production

Global imports and exports of aluminium and bauxite
Source: Author's own based on USGS 2020 for global bauxite, aluminium oxide and aluminium 2018, DERA 2019 for global net exports, oecd. world for net global imports 2017

Contribution to the Sustainable Development Goals

Potential to create employment in rural areas.

Potential infrastructure development through mining and associated sectors.

The high rate of recycling of aluminium products and products containing aluminium is already contributing to sustainable production and consumption.

As a light metal in the transport sector, aluminium is a factor in climate change mitigation.

Development-policy risks

Health:
Health risks can result from a lack of occupational health and safety and air pollution resulting from dust [18] [17] [19].

Environment:
The large areas of land needed for mining can result in forests being cleared. If not properly handled, seepage water and red mud from waste ponds or dried mounds can contaminate surrounding ecosystems [20] [18].

Social risks:
Within the scope of mining projects, there have been individual instances of (forced) resettlement [15]. Conflicts over water and land can also arise in the context of bauxite mining in arid or semi-arid areas [16] [17].

Climate:
The production of primary aluminium is hugely energy-intensive, but this varies widely around the world. In China, for instance, the energy used to produce one metric ton of aluminium (on average 21.6 t CO_2 equivalent) is far higher than in Europe (on average 9.7 t CO_2 equivalent) [21].

Most of the energy used in the manufacturing process results from the use of electrolysis, which is hugely energy-intensive. Some 15MWh of electricity is used to produce one metric ton of aluminium. That would power a two-person household for about 5 years [22].

Examples of German development cooperation activities

The development of a compensation standard for mining and the promotion of community-based monitoring within the scope of the GIZ project Regional Resource Governance in West Africa with a direct link to bauxite extraction in Guinea.

Interesting facts [23] [24]

- Aluminium is the most abundant metal element on Earth. It accounts for about 8% of the weight of Earth's crust, but a large percentage of this cannot be economically exploited.
- Although aluminium oxidises, it does not rust like iron, since the aluminium oxide on the surface of the metal forms a protective layer that prevents any further oxidation.
- Pure aluminium does not occur naturally.
- Aluminium reflects some 98% of infrared radiation.
- Only about 5% of the energy needed to produce pure aluminium from ores is needed to recycle aluminium.

Fig. 14: Bauxite mining in Waipa, Australia.

Fig. 15: Graphite is mined in both open-cast and underground mines.

Graphite

Main producer countries of natural graphite [25]

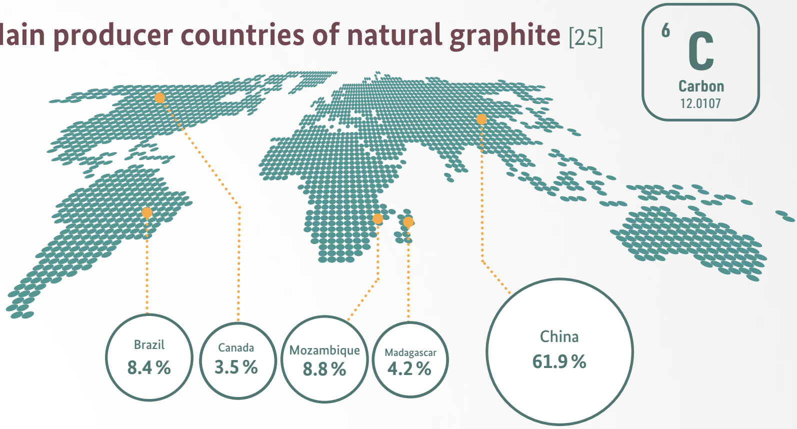


Fig. 16: China mines more natural graphite than any other country.
In future some African countries could become increasingly important in graphite mining.

Supply chain

Two sources are pivotal for the graphite market:

1. Natural graphite which is mined
2. Synthetic graphite, which can be produced by converting carbons via heating and chemical processes.

In battery production, both natural and synthetic graphite are used. Generally a mix of the two types of graphite is used. Synthetic graphite is a higher-quality product, but the quality of natural graphite can be enhanced with the help of a number of processes. For years China has dominated the world market in the production of natural graphite.

Graphite is used in the manufacturing of anodes. Either the anode material is fitted into batteries directly in China, or it is exported to South Korea or Japan, which also have leading battery manufacturers. In 2017 the largest importers were the USA, South Korea, Germany and China [26].

In recent years there have been increased exploratory efforts outside China. In particular in Mozambique and Tanzania are large reserves and resources, some of which are currently mined. Production could be increased here in future.

Contribution to the Sustainable Development Goals

Graphite mining, in Mozambique for instance, is an important economic factor at regional level.

Industrial graphite mining can generate more revenue through taxes and royalties. Properly used, these can make a contribution to poverty reduction.

Job creation in rural areas reduces the rural-urban exodus.

Infrastructure development through mining and associated sectors.

Development-policy risks

Graphite mining entails various risks specific to mining.

Health:
Graphite is not toxic, but adverse health impacts can result from other minerals that occur along with graphite or from the inhalation of fine particles of graphite during extraction and processing [27]. Modern dust control systems can largely mitigate impacts on air quality caused by dust emissions. In some countries, such as Sri Lanka, graphite is sometimes mined on a small scale, where the typical problems of artisanal and small-scale mining can be seen, in terms for instance of occupational safety.

Environment:
There are reports from China of black dust covering surrounding villages, drinking water being contaminated and harvests destroyed. Overall, environmental legislation and monitoring of enforcement has improved significantly in China in recent years. As a result, the environmental impacts of graphite mining have been reduced and some of the most environmentally hazardous mines have been closed.

Climate:
The production of synthetic graphite uses a lot of energy, which can result in high CO_2 emissions, depending on the energy source used [28].

Examples of German development cooperation activities

- In Mozambique, BGR is implementing the technical cooperation project Strengthening Public Management of the Mining Sector in Mozambique II. The project is enhancing the technical expertise of the Ministry of Mineral Resources and Energy and its downstream authorities.
- In 2019 the CONNEX Support Unit provided support in Mozambique for contractual negotiations relating to a graphite project.

- **In Mozambique, the Balama Mine currently has the largest capacity of any graphite mine anywhere in the world.**
- **Graphite consists of pure carbon, just like diamonds.**
- **Graphite is also used to produce 'lead' pencils.**

Fig. 17: Graphite is also mined in Germany.

Source: © BGR

Fig. 18: In some regions, small-scale mining is an important economic factor for the local population.

Cobalt

Main producer countries [29]

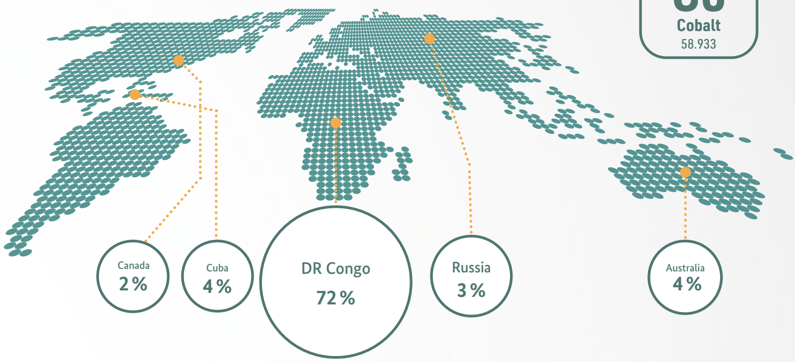


Fig. 19: In 2018 about 75% of global cobalt production came from large-scale mining operations. Artisanal and small-scale mining was responsible for about 13% of the total.

Supply chain

A large percentage of cobalt concentrates and intermediary products (hydroxides) are exported from the Democratic Republic of the Congo to China. Most of them occur as secondary products in nickel and copper mining. They are processed there for use in battery manufacture and further processing. Battery components are currently manufactured and assembled mainly in China, Japan and South Korea. From there, the batteries are exported worldwide and are mainly used in the manufacture of high-tech products and in the automobile industry [6].

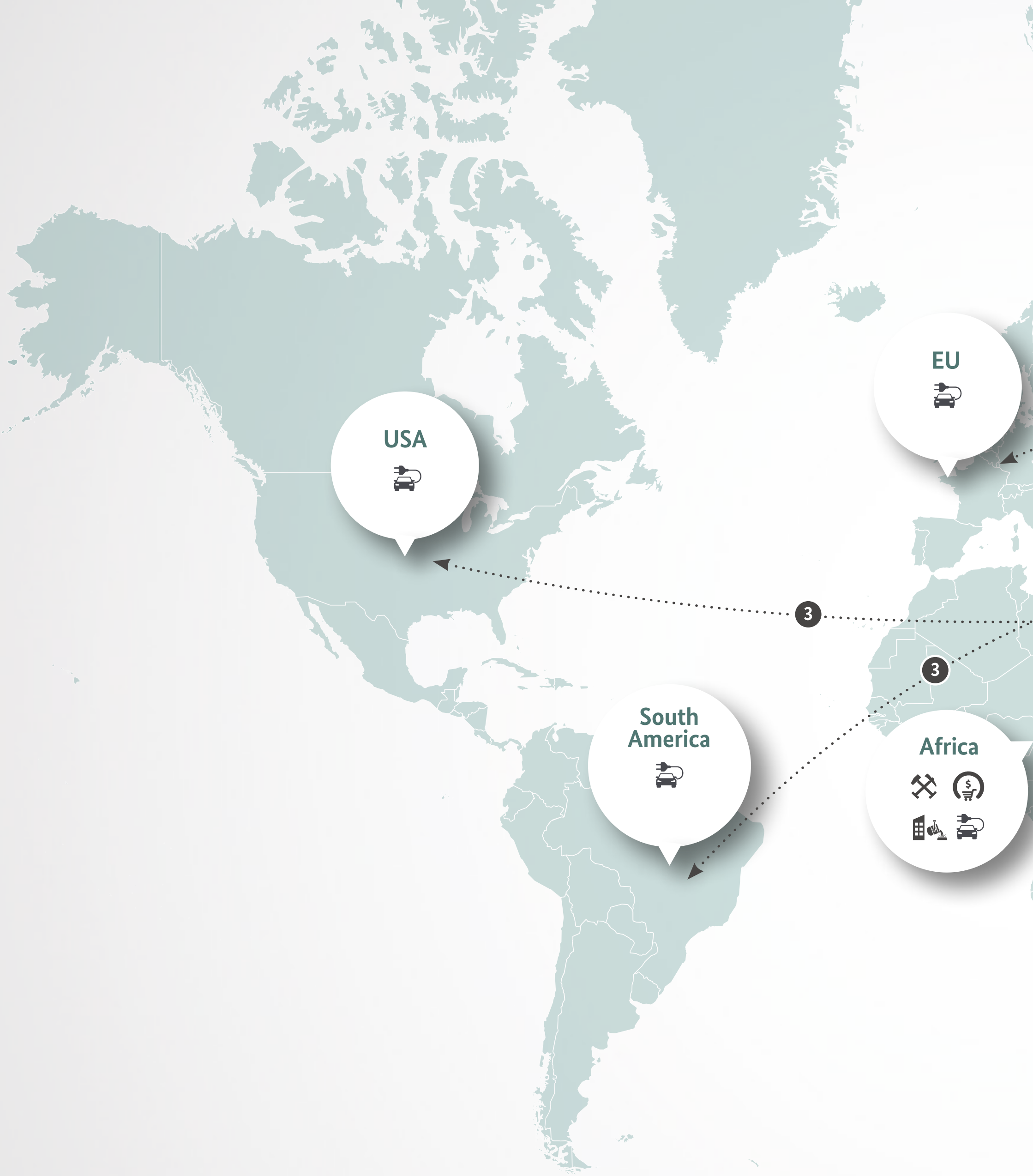
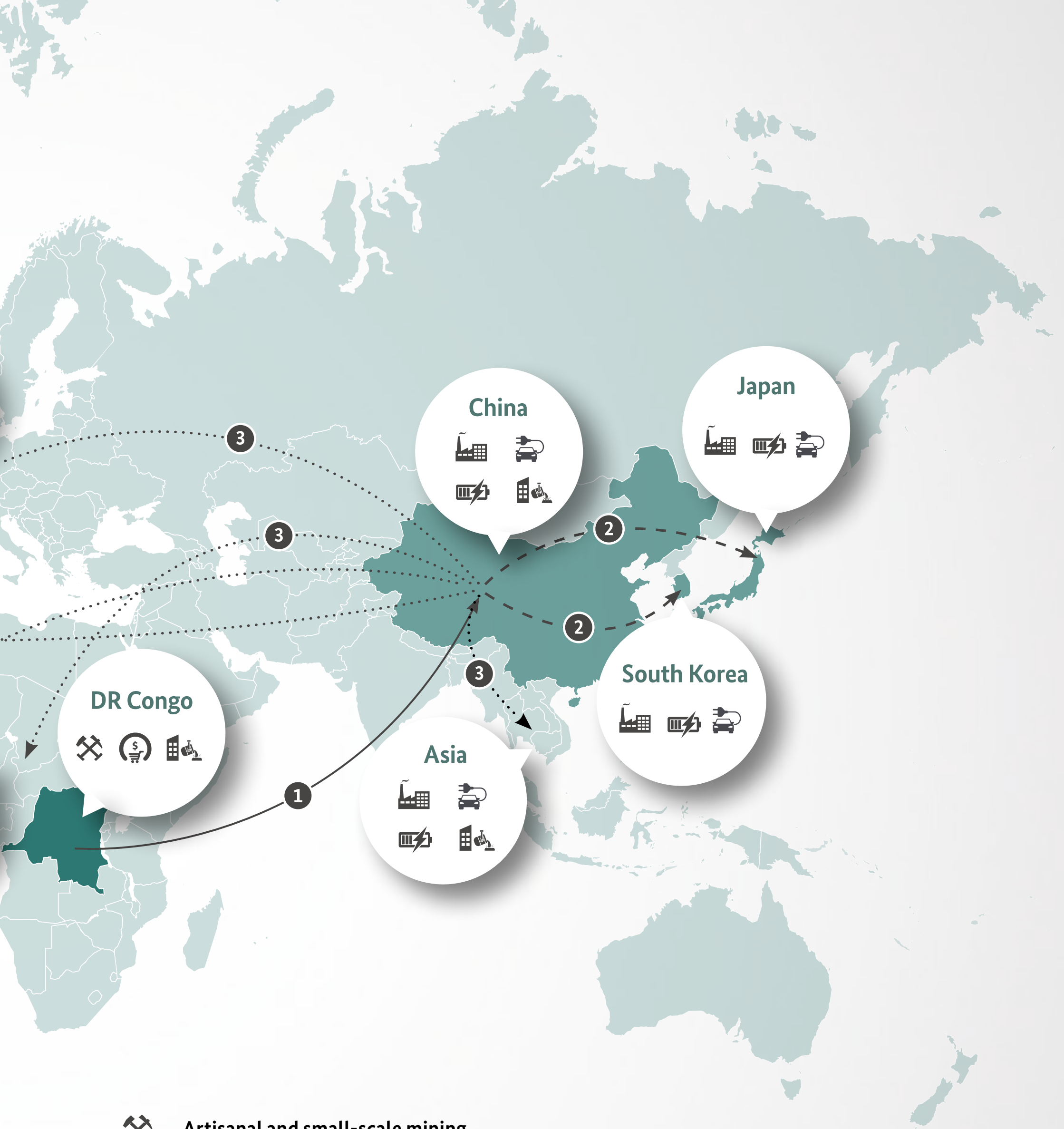


Fig. 20: Cobalt trade flows from artisanal mining in the Democratic Republic of the Congo to the global market.

- 1 — Export of cobalt from artisanal and small-scale mining to China for refining.
- 2 — Cobalt used in Asia to manufacture lithium-ion batteries.
- 3 — Lithium-ion batteries used in electric vehicles and other high-tech products.



Artisanal and small-scale mining

Trading centre

Refinery/metallurgical plant

Manufacture of battery components

Battery manufacture

Final product

Contribution to the Sustainable Development Goals

The value of total cobalt production in the Democratic Republic of the Congo fluctuates between USD 2-3 billion.

Jobs for about 100,000[4] people in the artisanal and small-scale mining sector and an estimated 100,000 more in the LSM sector make a significant contribution to reducing poverty.

Employment in rural areas counters 'rural exodus'.

Infrastructure development through mining and associated sectors.

4 During booms employment can rise to 200,000 but numbers fluctuate strongly.

Development-policy risks

Environment:
Artisanal and small-scale mining results in environmental damage, e.g. because there is no rehabilitation. Environmental problems also occur in large-scale cobalt mining in the form of hazardous waste left at abandoned mines.

Health:
The lack of occupational health and safety measures in artisanal and small-scale mining poses health risks which can be fatal.

Social risks:
Human rights abuses are seen in artisanal and small-scale mining, including the worst forms of child labour. Unfair payment of miners is another social risk in artisanal and small-scale mining. In large-scale mining there is a risk of corruption and there have been cases of (forced) resettlement.

Examples of German development cooperation activities

- Support for responsible cobalt mining in the artisanal and small-scale mining sector through the project Strengthening of Control in the Mining Sector of the DR Congo III:
    - Support for cobalt cooperatives in the Copperbelt
- Production of a *study that analyse the artisanal copper/cobalt sector in the DR Congo.*
    - Implementation of the Certified Trading Chains (CTC) system.

- **I n 2019, 50-60 % of cobalt mined was used in batteries.**
- **Various cobalt chemicals were used as dye in ancient times because of their lustrous blue colour (cobalt blue).**

Fig. 21: Artisanal cobalt mining in the Democratic Republic of the Congo.

Source: © BGR

Fig. 22: Chuquicamata is a large-scale industrial copper mine in the Atacama Desert in the northern region of Antofagasta, Chile.

Copper

Main producer countries [29]

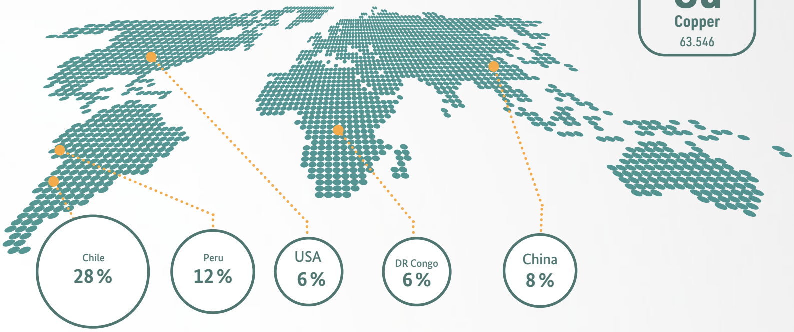


Fig. 23: Copper is currently mined in over 50 countries.
Recycling plays a comparatively large part in global supplies.

Supply chain

Upstream copper supply chains (from the mine to the refinery) are relatively easy to trace, whereas the downstream chains up to the manufacture of final products are relatively hard to trace. Copper is mined in over 50 countries and, in comparison to other resources, recycling plays a comparatively large part in global supplies[5].

Important production processes and intermediary products post-mining include processing the copper-containing minerals to make copper concentrates (containing up to 30% Cu), copper blister (containing up to 98% Cu) and copper anodes (containing up to 99.5% Cu) and the subsequent refining to produce copper that is 99.9% pure; and the semi-fabricated products[6] made of refined copper including copper foil used in lithium-ion batteries, wires and busbars.

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5 Depending on the degree of purity, copper scrap is used in semi-fabricated copper products or fire-refined copper.

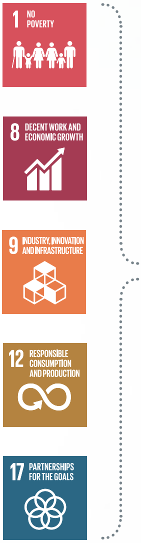
6 Semi-fabricated copper products include wire, rods and pipes, which are part of a finished product.

In 2018 most copper was refined in China (38%), Chile (10%) and Japan (7%) [30]; in the same year, 80% of semi-finished products came from Asia. The main products in the global trade in copper are copper ores and concentrates, refined copper, copper scrap and semi-fabricated copper products.

Table: Main importing and exporting countries (2018) with examples of product categories (volume not value) [31].

Category	Export	Import
Ores & concentrates	1. Chile 2. Peru 3. Australia 4. Mexico 5. Indonesien	1. China 2. Japan 3. Spain 4. South Korea **5. Germany**
Copper blister & anodes	1. Zambia 2. Chile 3. Bulgaria 4. South Africa 5. Spain	1. China 2. Belgium 3. India **4. Germany** 5. Canada
Refined copper	1. Chile 2. Russia Federation 3. Japan 4. Kazakhstan 5. Australia	1. China 2. USA **3. Germany** 4. Italy 5. Taiwan
Semi-fabricated copper products	**1. Germany** 2. China 3. Taiwan 4. South Korea 5. Italy	1. China 2. India 3. USA 4. Italy **5. Germany**

Contribution to the Sustainable Development Goals



Important source of income for many states. Between 1996 and 2015, copper mining accounted for 10% of Chile's annual GDP on average [32]. In 2017, mining accounted for 31.4% of GDP in the Democratic Republic of the Congo, 25.9% in Zambia, 16.6% in Chile, and 15.5% in Peru [33].

Job creation: in Chile mining provided work for 2.9% of the workforce on average between 2010 and 2016 [34].

Copper is an excellent conductor of electricity and heat, making it indispensable for the energy shift and transformation of the traffic and transport sector.

Development-policy risks

Environment [35]:
Water consumption is high in copper mining and refining and the procedures used produce acid mine drainage. There is a risk that tailing dams overflow or burst. Additional environment risks include the toxic emissions released during smelting and refining.

Climate:
A lot of energy is used to mine copper. In Peru, for instance, one of the country's largest copper mines consumes 9% of the country's electric power.

Social risks [36]:
Copper mining has been known to ignite social conflicts with surrounding communities. Copper is often mined on indigenous land. This can result in violations of indigenous rights. A lot of land is also often needed for copper mining. This can lead to forced resettlement. And copper mining can be linked to illicit financial flows.

Fig. 24: Copper plates are stored at the Lomas Bayas mine in Chile's Antofagasta region.

Examples of German development cooperation activities

- The BGR-GIZ project Regional Cooperation for the Sustainable Management of Mining Resources in Andean Countries (MinSus) is supporting Andean countries in adopting responsible practices in copper mining.
- Support for initiatives to develop and trace supply chains and certification systems.
- Promoting multi-stakeholder dialogues and active participation by minorities, local communities and civil society in decision-making processes.
- Technology transfer and fostering innovation to reduce the ecological footprint of mining activities.

- **Copper is second only to silver in terms of its ability to conduct electricity and heat and is the third most traded metal in the world after steel and aluminium [30].**
- **Copper can be recycled with no loss of quality. Less energy is needed to recycle copper than to produce primary copper.**
- **The average electric car contains about 80 kg of copper, which is about three times as much as is needed in a car with an internal combustion engine (about 25 kg) [37].**

3
Li
Lithium
6.94

Fig. 25: Salinas Grandes salt desert in Jujuy province in northwest Argentina.

Lithium

Main producer countries [38]

3
Li
Lithium
6.94

Fig. 26: Lithium is currently commercially extracted from hard rock mines and brine reservoirs.

Supply chain

The lithium supply chain begins with extracting lithium. Currently lithium is sourced from hard rock mines (e.g. in Australia) and from underground brine reservoirs under salt flats (e.g. in Chile, Argentina and China).

Mineral concentrates and lithium brines[7] are processed to produce lithium carbonate, lithium hydroxide, and less frequently lithium chloride. Mineral concentrates are mostly processed in China (>90 %). Brines are processed locally by the same companies that extract the brine [7]. Lithium brine is pumped to the surface through bore holes (Li content of up to 0.2%) and then passed through a series of evaporation ponds to increase the lithium content to up to 6%. This enriched lithium brine is then processed in a chemical plant to produce (mainly) lithium carbonate. Lithium carbonate and lithium hydroxide are used in the manufacture of cathodes.

Mining / extraction → Lithium chemicals → Cathodes → Batteries/ battery cells → Battery modules/ assembly → Battery Electric car

7 Watery salt solution.

Contribution to the Sustainable Development Goals

Mining is an important source of income for many states, e.g. in 2017 mining generated 16.6% of Chile's GDP, while in Zimbabwe the figure was 13.6 %. [33]

Job creation, e.g. one of the lithium producers in Chile employs almost 5000 people. [33]


Development-policy risks

Environment:
Lithium extraction regularly triggers debates regarding the impacts of brine extraction on the water table, lagoons in the surrounding area as well as flora and fauna in arid areas [39].

There are potential risks to water supplies when lithium is mined in hard rock mines in arid areas.

Social risks:
When lithium is extracted from brine reservoirs in particular, there can be violations of indigenous rights. Social conflicts can also arise over the use of land and natural resources.

Examples of German development cooperation activities

- The BGR-GIZ project Regional Cooperation for the Sustainable Management of Mining. Resources in Andean Countries (MinSus) is fostering a regional exchange of best practices for responsible mining, including the extraction of lithium.
- Studies on aspects of lithium extraction, including a study on the governance of the lithium sector in Bolivia.
- Through GIZ, BMZ has supported the establishment and implementation of the World Bank's Climate Smart Mining Strategy from the start. As part of the strategy, the World Bank is planning a project to illustrate the carbon footprint of lithium.

- **Bolivia's Salar de Uyuni is thought to contain the world's largest lithium deposit, but it has not yet been proven that it can be exploited economically. Lithium is currently produced only in Bolivia's neighbours, Argentina and Chile.**
- **In Europe, lithium projects are being developed; the European Commission aims to enable Europe to meet 80% of its own demand for lithium as of 2025.** [40]
- **Lithium hydroxide is generally used in the manufacture of 'high performance' cathodes.**
- **Battery grade lithium compounds are needed to manufacture cathodes; they must have a higher level of purity than chemicals used to manufacture glass or lubricants.**

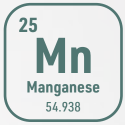
Fig. 27: Brine pools for lithium mining.

©DERA 2015

Fig. 28: A furnace at Mogale Alloys, South Africa.

Manganese

Main producer countries [25]



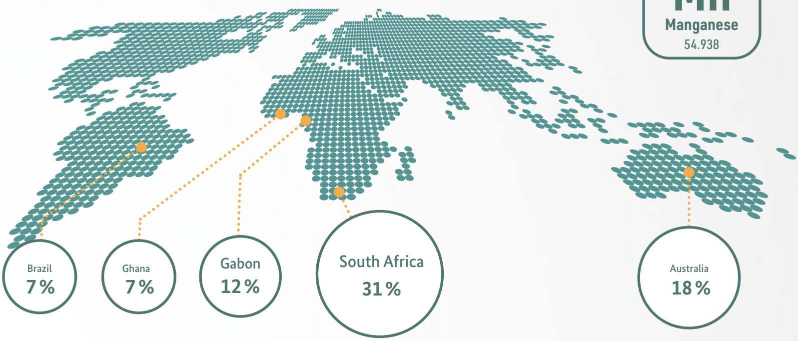


Fig. 29: Most manganese is mined on an industrial scale. Artisanal and small-scale mining plays a very minor part.

Supply chain

Manganese is generally mined in underground or open-cast mines on an industrial scale, and then processed in a metallurgical or chemical plant. The world's largest producers of manganese ore are South Africa and Australia. Most manganese ore is then processed in China, which is the largest importer of manganese ore. [41]. In China, manganese ore is processed to make intermediate products for steel manufacture (the most important use of manganese) and battery production. While intermediate products for steel, especially ferromanganese and silicomanganese, are sold worldwide, most of the intermediate products for battery manufacture are used in China itself, or in Japan and South Korea, where the batteries are manufactured [42]. The final products (e.g. LIBs) are then sold worldwide.

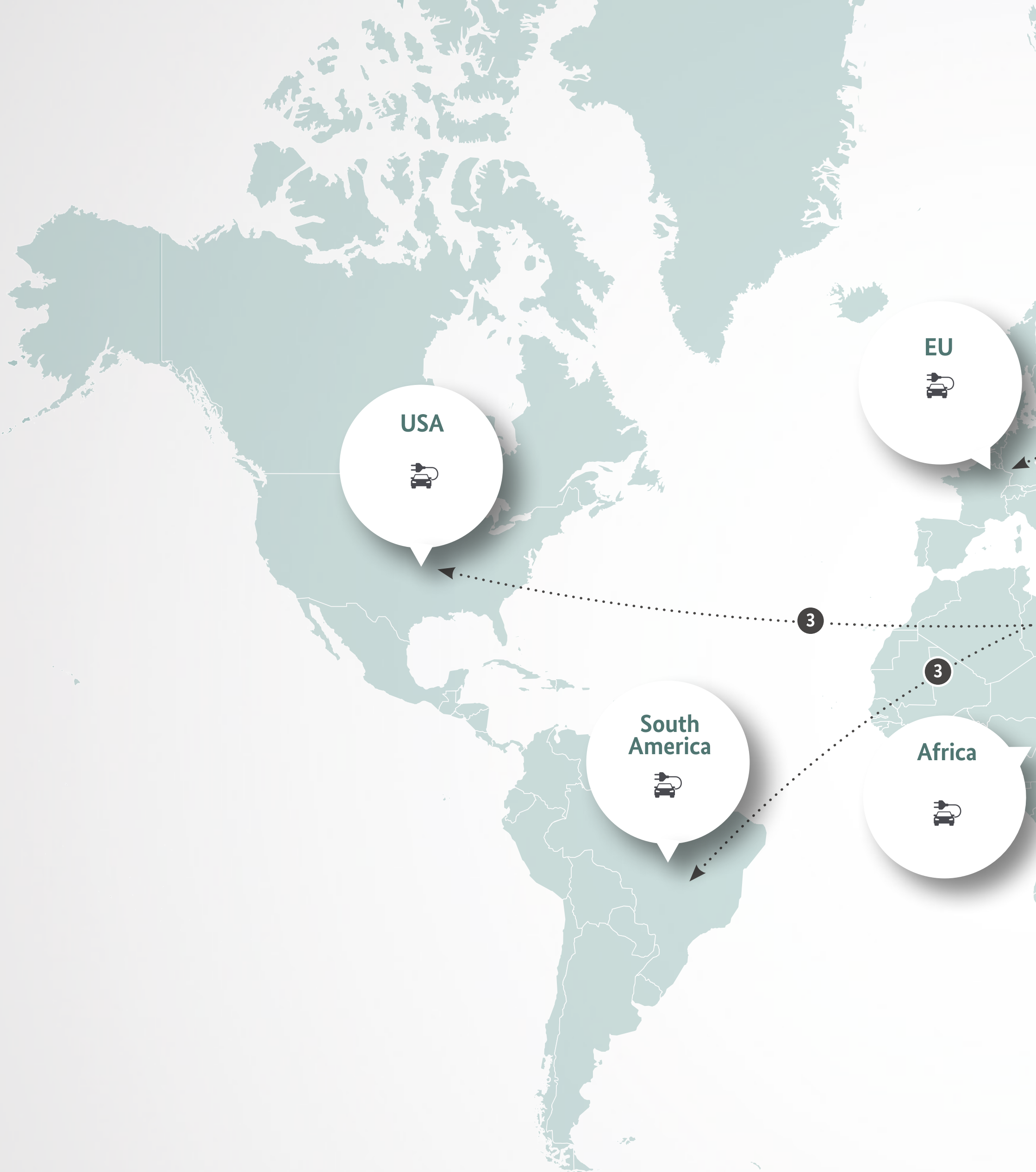
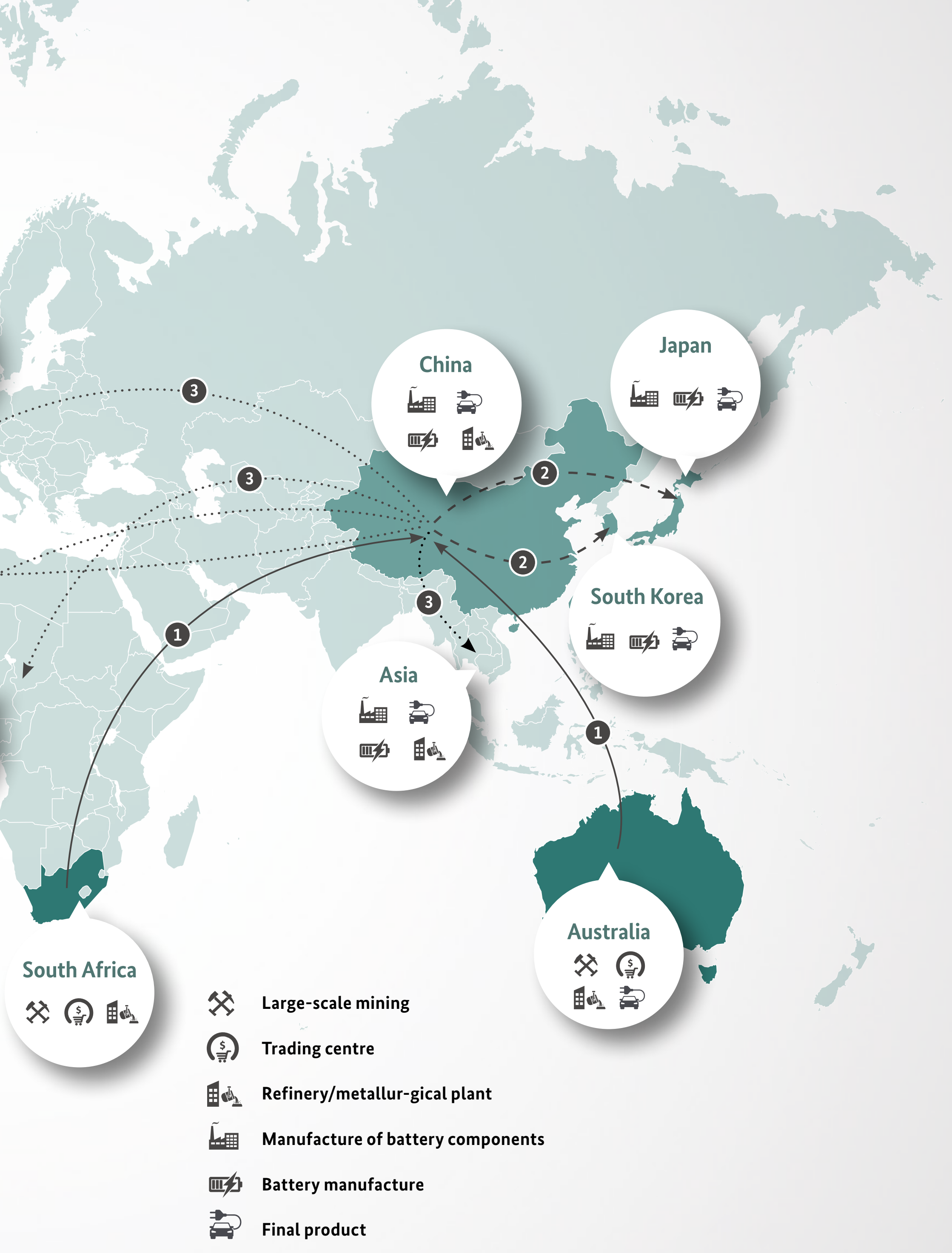


Fig. 30: Simplified supply chain for manganese in battery manufacture.

—1— Manganese ores from large-scale mining exported to China for processing.

- -2- - Intermediate products used to produce lithium-ion batteries in China, Japan and South Korea.

·····3····· Lithium-ion batteries used globally in electric cars and other high-tech products.


China
Japan
South Korea
Asia
Australia
South Africa
1
2
3
Large-scale mining
Trading centre
Refinery/metallur-gical plant
Manufacture of battery components
Battery manufacture
Final product

Contribution to the Sustainable Development Goals

Manganese mining is a very considerable economic factor in some countries, including Gabon and South Africa.

Manganese ore is Gabon's second largest export, accounting for about 21% of all exports (USD 1.2 billion); it plays an important part in the country's economic development [43].

Although artisanal and small-scale mining plays a lesser part in manganese production, it can boost local economic development in some areas (e.g. Indonesia and Myanmar).

Large-scale mining boosts tax revenues and helps develop infrastructure and associated sectors of the economy.

Development-policy risks

Since manganese is mined almost exclusively on an industrial scale, that is where the greatest development-policy risks can be seen.

Health:
In the vicinity of industrial plants there can be exposure to higher levels of manganese, which can constitute a health hazard for children in particular (e.g. impaired growth and skeletal deformities) [44].

Environment:
The potential environmental impacts of deep-sea mining, which is currently being explored, cannot be predicted yet.

Social risks:
Exploration of new mining areas has in individual cases been seen to result in (forced) resettlement.

The areas currently being explored by BGR for potential deep-sea mining alone could be sufficient to meet Germany's demand for manganese (2018) three times over as well as 80% of its demand for cobalt, which is also found in manganese nodules [45]. But little is yet known about the deep-sea ecosystem. Deep-sea mining is a risk to maritime ecosystems, so research is needed to identify the potentials and risks of deep-sea mining more precisely.

Fig. 31: Manganese production at Wessels Mine in South Africa.

Fig. 32: Nickel production in Norilsk, Russia.

Nickel

Main producer countries [29]

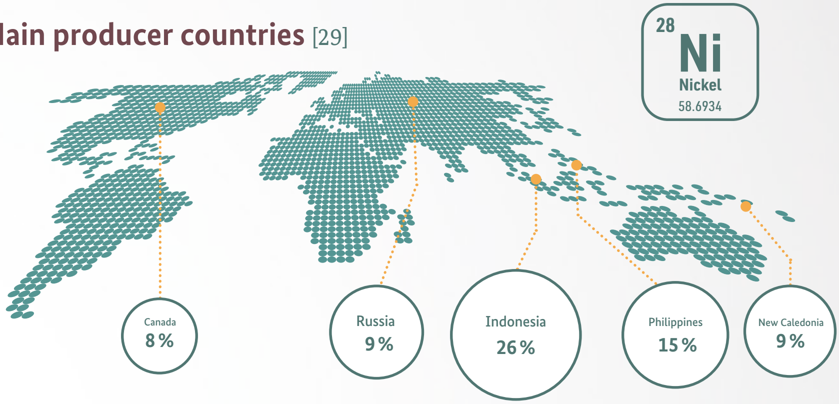


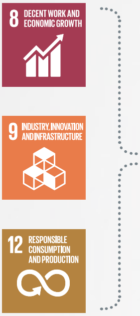
Fig. 33: Nickel reserves are spread over a wide geographical area.

Supply chain

Global nickel reserves are spread over a wide geographical area, making global supply chains complex and long. Nickel laterites and nickel sulphides are mined on an industrial scale in around 30 countries spread across six continents and processed to produce Class 2 nickel (in particular nickel pig iron and ferronickel – containing less than 99.8% nickel) and Class 1 nickel (containing a minimum of 99.8% nickel) [46]. As well as Class 1 nickel, a number of intermediate nickel roducts (e.g. nickel matte) from primary and secondary raw materials are used to produce nickel sulphate, which is the key material used to produce cathodes for lithium-ion batteries. These products are produced in numerous countries and traded globally.

In 2017, Canada, the Netherlands (as a hub only), Russia and Norway were the largest exporters of Class 1 nickel traded on the London Metal Exchange (LME) and the Shanghai Futures Exchange (SHFE) [47].

Contribution to the Sustainable Development Goals



Potential to create employment in rural areas.

Potential infrastructure development and value chain development through mining and associated sectors (e.g. Indonesia).

Development-policy risks

The greatest development-policy challenges are related to nickel mining and processing.

Health:
A lack of occupational health and safety measures during mining and processing of nickel ores and concentrates [48] [49].

Environment:
Contamination of drinking water where there is a failure to comply with necessary safety procedures in the mining and processing of nickel. More research is needed on the potential adverse environmental impacts of possible future mining scenarios, such as deep-sea mining [50] [51] [52].

Social risks:
Human rights violations in the context of individual (forced) resettlement schemes and concomitant measures related to mining projects [53] [54].

Examples of German development cooperation activities

Support for the EITI (Extractive Industries Transparency Initiative) multi-stakeholder group in the Philippines. The Philippines have included nickel in their EITI reporting in order to enhance accountability and financial transparency in this important part of the national extractive sector.

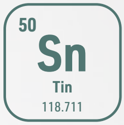
- **Nickel is used in various coins in the US, UK and the euro zone.**
- **The term 'nickel' comes from the German word 'Kupfernickel' or Devil's copper.**
- **After iron, nickel is the second most commonly found element in the core of the Earth.**

Fig. 34: Massive nickel sulphide ore (Leinster Western Australia).

Fig. 35: Tin can also be found in sediments like sand or gravel in coastal waters.

Tin

Main producer countries [29]



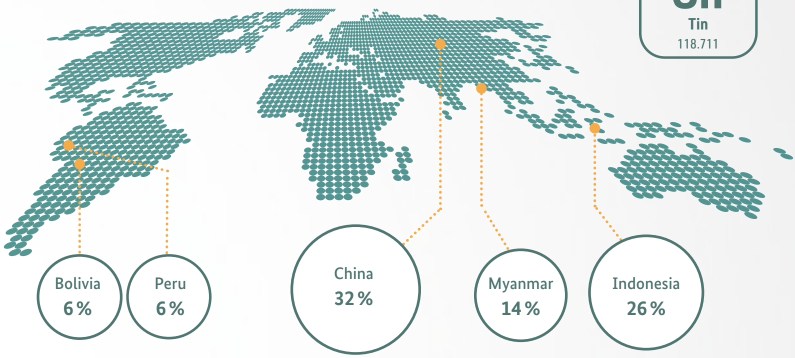


Fig. 36: Tin deposits are found in hard rock, where it is generally industrially mined, and in placer deposits in sediments like sand and gravel on land and in coastal waters where it can be extracted manually or with minimum mechanisation.

Supply chain

Tin is used to connect and coat electric cables, wires and printed circuit boards. Tinplate is used for connections, battery contacts, battery casing and protective casings in electrical and electronic engineering. Tin is not used at present on an industrial scale in batteries for electric mobility. Current research indicates that tin could be used in lithium-ion batteries in future. Tin could help to significantly increase energy density and operating safety.

The average size of companies in tin mining is comparatively small. A significant percentage of global tin production comes from artisanal and small-scale mining, which is estimated to account for about 27% of the total output. Informal and illegal tin mining is widespread on some Indonesian islands, and is closely interconnected with the formal sector through a complex web of intermediaries. Only tin metal may now be exported from Indonesia.

In 2014 the three largest exporters of tin ores and concentrates were Myanmar, Australia and Nigeria [55] [56]. The main importers were China, Malaysia and Thailand [57].

Contribution to the Sustainable Development Goals

Potential to generate employment in rural areas.

Labour-intensive artisanal and small-scale mining provides a livelihood for many people in developing countries. The often informal nature of this sector makes it difficult to put a precise number on the workforce. In Myanmar between 10,000 and 12,000 people work in artisanal tin mining. In Indonesia the total is between 40,000 and 60,000. Globally, some 250,000 people work in small-scale tin mining.

The Indonesian mining regions on the islands of Bangka and Belitung have some of the lowest poverty rates in Indonesia [58].

Many migrant workers from other parts of Indonesia work in tin mining; with what they earn they support their families in other parts of the country.

Development-policy risks

The greatest challenges are often seen in artisanal and small-scale mining, which accounts for about 27% of all tin mining.

Environment:
Tin mining can impact on the environment. It can destroy coral reefs and disturb the water balance [60].

Health:
In artisanal and small-scale mining in particular, the lack of occupational health and safety can result in injuries, some of which are fatal [59].

Conflict financing:
Tin is a 'conflict mineral'. In Myanmar a rebel group calling itself the 'Wa-Armee' finances itself partly from tin mining. The 'Wa-Armee' includes child soldiers [61]. Most of the tin mined by the group is exported to China, where it is processed [62]. Tin is also mined in the Democratic Republic of the Congo and linked to conflict financing in the region [63]. This tin is smuggled into Rwanda and Burundi and exported from there.

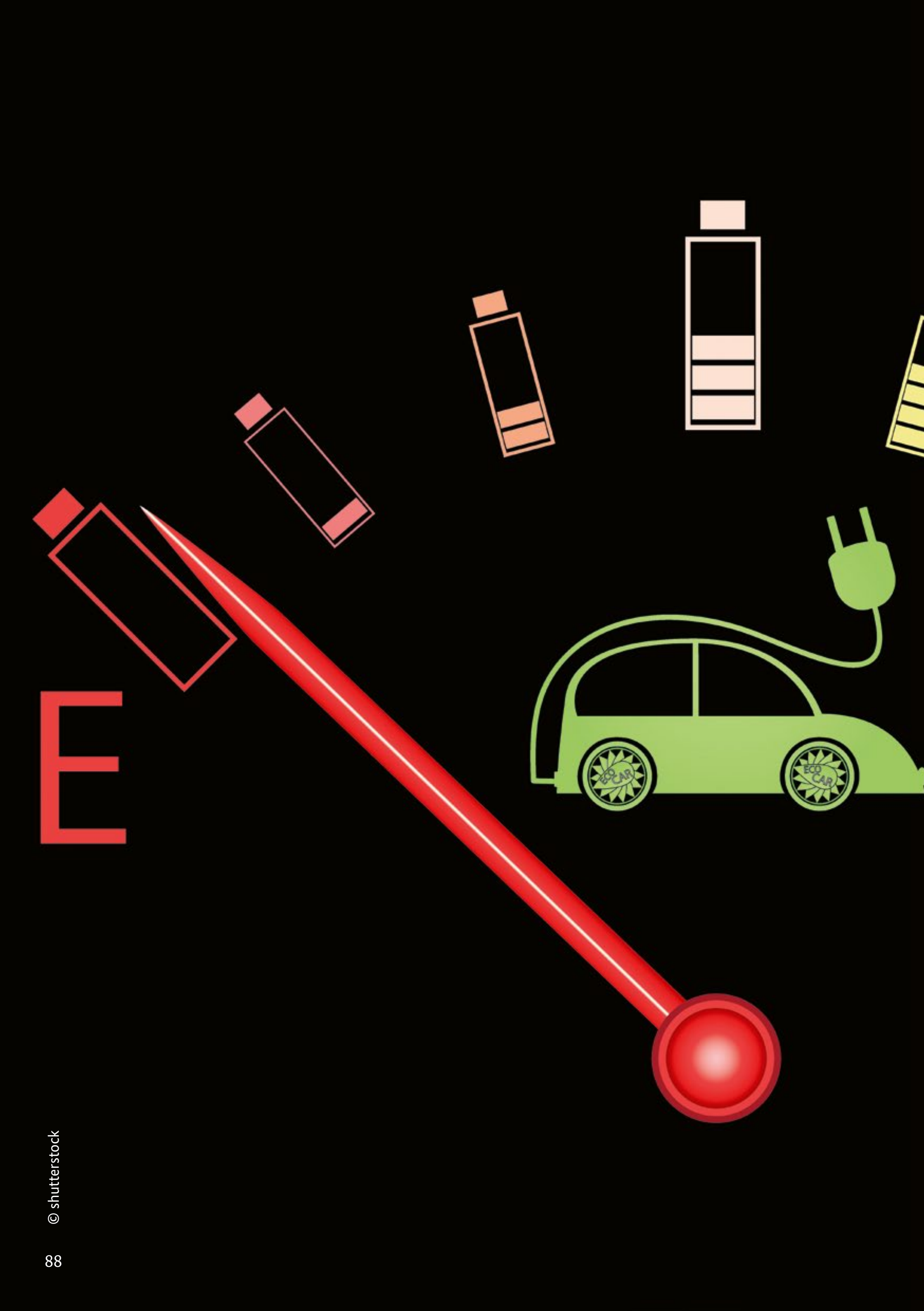
Social risks:
Child labour is a facet of tin mining that is regularly criticised.

Examples of German development cooperation activities

- In the east of the Democratic Republic of the Congo, BGR is implementing a project to establish a certification system (CTC, Certified Trading Chains) for tin.
- BMZ is a member of the European Partnership for Responsible Minerals (EPRM), which promotes projects in artisanal and small-scale tin mining, e.g. the Tin Working Group in Indonesia.
- The Programme to Support the International Conference on the Great Lakes Region (ICGLR) aims to stem trade in illegally mined materials in signatory states of the ICGLR.

Tin can be recycled any number of times with no loss of quality, so recycling will continue to play a part in tin supply in future.

Fig. 37: Cassiterite (here in crystalline form) is the most important source of tin.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Recycling potential

Once an electric vehicle battery’s primary use ends, it can either be repurposed, for instance for stationary energy storage, or it should be recycled. In Europe, the infrastructure for both options is still being developed. Developing countries and emerging economies have few if any capacities.

The battery modules from electric vehicles, which either no longer have the required capacity or which have defective cells, can be repaired and used again as a complete battery pack. Alternatively, only the well-preserved cells can be refurbished or refitted [64]. Cells that can no longer be used in electric vehicles can be repurposed for second-life applications in stationary energy storage on a small or larger scale, e.g. energy storage for renewable energy in a domestic setting [65]. Individual components can also be removed and re-sold as spare parts. These processes are labour-intensive and the different manufacture and packing procedures used (because of fire hazard regulations for instance) make it more difficult to process batteries and automate procedures [66].

Individual raw materials can be recovered from non-reusable cells. The batteries have to be manually stripped down to their individual components. As of a certain recycling capacity, partial automation pays off, but here too the stripping down is made more difficult by the different manufacturing and packing processes [67]. Mechanical, pyrometallurgical or hydrometallurgical processes are used to remove and collect the materials from the cells. These processes are complex, use a lot of chemicals, and entail high CO_2 emissions. In a laboratory setting they can now be used to recover not only metals but also graphite, electrolytes and conducting salts [68]. The efficiency of the procedures and the purity of the materials recovered vary widely. While aluminium, for instance, can be recycled very successfully, the recycling rates for lithium are extremely low, since it is neither technically possible nor economically viable to recover material of a quality that is suitable for use in cathode production. For optimum performance, the cobalt used in batteries also needs to be extremely pure, which limits the use of recycled cobalt.

For recycling companies, the value of a battery depends not only on the recycling costs and the legal framework, but also on the materials it contains, and thus on the current raw material prices. Technical progress in particular has pushed down the percentage of valuable metals contained in batteries. Lithium-cobalt-oxide batteries, which were in common use between roughly 1990 and 2010 but are no longer used today, were worth about EUR 8 per kilogram because of their high cobalt content (about 20%). The cathodes of modern NMC batteries have a cobalt content of between 2 and 6%, making them worth only about EUR 4.70 to 5.50 per kilogram. Cobalt-free batteries are worth only about EUR 2 per kilogram (2019). Combined with the greater complexity of the recycling process, this factor impacts on the economic interest in recycling [69]. Legal product specifications regarding the percentage of secondary raw materials that must be used have a great influence on the demand for and the economic viability of recycling.

One major difficulty at present in the recycling of consumer electronics (including mobile phones) is the collection of batteries. Batteries are often fitted in such a way that consumers can not remove them. If a device is not returned to a recycling company contracted by the manufacturer, but sold abroad to be used or recycled there, it is no longer available on the recycling market of the original country [69].

This means that manufacturers cannot meet their obligations to ensure that products are properly disposed of. Large quantities of the batteries that ought to be recycled in Europe are exported to Asia and recycled there.

Although the first major recycling stations in Germany, Poland, Sweden and Hungary are planned or already being developed, China ranks first by a long way in the recycling of cells, cathode and anode materials. While Chinese companies recycled about 70% of battery cells in 2018, the figure in Europe was under 5%. This is partly because China has a very much larger market, recycling is encouraged by the Chinese state, and companies have easy access to material for recycling. Recycling and manufacture are closely linked. The Chinese Ministry of Industry and Information Technology (MIIT), for instance, obliges manufacturers of electric vehicles to set up and standardise recycling plants for batteries [70]. Although the EU is a mature market in terms of traditional battery recycling, it has only one plant that combines lithium-ion battery manufacture and recycling [71].

A clear framework, norms and uniform industrial standards are an important step towards ensuring the more effective recycling of lithium-ion batteries when they come to the end of their first-life application. Battery lending systems and battery deposit schemes are another way of improving collection. Battery lending means that the battery does not become the property of the user, but that it is provided by the manufacturer for a fee. Deposit schemes provide financial incentives to ensure that batteries are returned to the manufacturers, enabling them to meet their obligations and guaranteeing technically appropriate recycling. Ensuring that batteries are returned to manufacturers also facilitates investment in the recycling capacities of manufacturers and their contractual partners.

All in all, recycling provides interesting opportunities for countries with advanced recycling technology in order to perhaps reduce the pressure on certain materials in the wake of rising demand. However, even if recycling is stepped up significantly, the rapidly expanding electric mobility market will mean continued strong demand for primary resources. This is particularly true of resources for which demand is rising most strongly, while there is little material available for recycling or repurposing. This is why additional political measures are also needed in order to foster energy efficiency, environmentally and socially acceptable procedures, and innovations. It should be ensured that the batteries used in electric vehicles can be safely and efficiently removed and recycled – not only in Europe, but in developing countries and emerging economies in particular, where used electric vehicles might often be exported. This is already widespread practice for vehicles with internal combustion engines. The export of used electric vehicles would pose new challenges for developing countries and emerging economies, particularly in terms of recycling batteries.

Examples of German development cooperation activities

- Within the PREVENT waste alliance, BMZ is promoting pilot projects in the field of recycling lithium-ion batteries in Africa.
- Germany is supporting the Government of Ghana in developing a sustainable electric waste management system.

European Green Deal: Sustainable batteries for a circular and climate-neutral economy

In December 2020, the European Commission proposed modernising the EU regulations for batteries. It will look at the entire battery value chain from primary raw material extraction to the circular economy. This new legal framework is to improve sustainability and make it easier to recycle batteries. This is the first initiative among the measures announced in the EU Circular Economy Action Plan. Batteries that are more sustainable throughout their life cycle are key to achieving the objectives of the European Green Deal. These will be mandatory requirements for all batteries (used in industry, automobiles, electric vehicles and electric and electronic devices) that are sold in the EU.

For the development of a more sustainable and more competitive battery industry in Europe and worldwide, the requirements are extremely important. They include the use of responsibly sourced materials, a minimum recycled materials content, a smaller CO_2 footprint, the setting of standards for performance, durability and designation, as well as collection and recycling regulations. Batteries sold in the EU are to be sustainable, effective and safe throughout their life cycle. This means that batteries are manufactured to minimise their environmental impact and using materials that have been mined or extracted in full compliance with human rights and environmental and social standards.

The battery regulation pursues the following objectives:

- Harmonise product requirements for batteries
- Minimise the environmental impacts of batteries
- Impose mandatory secondary (recycled) resource content
- ‘Close the circle’ by encouraging repurposing, and improving the collection and recycling of batteries
- Create legal certainty to encourage investment and raise the production capacity for sustainable batteries in Europe and beyond.

Substitution

Social, economic and environmental challenges along the value chains of individual resources mean that it can be advantageous to reduce the percentage of these materials used, or to substitute them completely. When assessing the feasibility of substituting individual materials it is important to know the purpose and the battery type. Any change in the composition will affect the properties and output of the battery, as well as its range and life span.

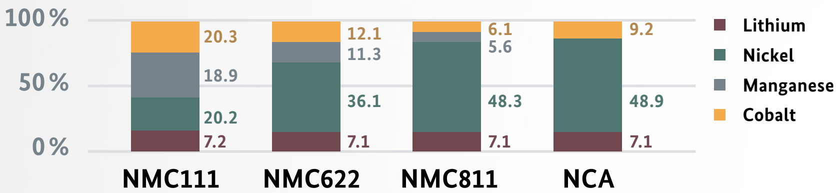

Fig. 38: Breakdown of materials used in LIBs with different cathodes.

Cobalt from the Democratic Republic of the Congo is the focus of public attention as a result of reports of child labour and hazardous working conditions. The negative image of cobalt and its price volatility were factors behind the drive to produce low-cobalt or cobalt-free batteries. The cathode of an NMC111[8] battery contains 20% cobalt. After the composition was changed, the cathode of the NMC811 battery now contains only 6% cobalt. Cobalt is replaced by a larger percentage of nickel [6]. This larger nickel content also provides for greater energy density. Today, batteries with cathodes with a nickel content of some 80% (e.g. Tesla's NCAs and NMC811 batteries) and on a lesser scale with a nickel content of some 90% are available commercially.

The lithium-iron-phosphate battery (LFP) has no cobalt, manganese or nickel in the cathode. It is deemed to be particularly safe, environmentally friendly and has other positive properties. However, the energy density, which is only about half that of NMC/NCA cells, limits the possible uses of the battery. It is more likely to be used in stationary energy storage or in electric buses than in electric cars [72].

Various research approaches are looking at new battery compositions and types.

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8 In an NMC111 cathode the ratio of nickel to manganese and cobalt is ~1:1:1, while in an NMC811 cathode the ratio is ~ 8:1:1.

This includes research into aluminium-ion batteries to facilitate a greater range and as a possible substitute for lithium. For the anodes, research scientists are also exploring ways of substituting graphite. These are not likely to be commercially viable for the next ten years, however [73].

At present batteries need a stable battery casing and a base plate to protect the cells. Both of these are made of aluminium in many cases. The new packing procedures, high performance alloys and the development of solid-state batteries will make it possible to significantly reduce the materials used here [74]. Solid-state batteries need no heating or cooling and thus allow for further savings.

Only innovative research can reduce the volume of materials used in a battery. Technical progress has led to major efficiency gains in recent years and made possible a whole series of battery compositions. When deciding on the resources to be used in a battery, social and economic factors should be considered alongside technical and economic interests. Materials that are more critical from a development-policy stance could be reduced or avoided entirely. The crucial factor here, however, is not to lose sight of the fact that efforts to address the possible adverse consequences of mining one mineral might simply shift the problems to the mining of the substitute.

Decisions of this sort can also have major development implications for the producer countries, since mining is often the only source of income for many people in the relevant areas. Rather than focusing exclusively on substitution, the priority should be to foster sustainable mining in compliance with environmental and social standards.

It is not yet clear what battery type will become generally accepted. The high level of political attention accorded to electric mobility and the concomitant active research will make for increasing technical progress and innovation in the years to come.

Glossary

Active materials: The active materials of a battery are the chemically active components of the two electrodes of a cell and the electrolyte between them.

Artisanal and small-scale mining (ASM): Artisanal and small-scale mining is the extraction of minerals using simple, non-industrial methods.Small-scale exclusively manual mining is also termed artisanal mining. Artisanal and small-scale mining is a largely informal sector. In many resource-rich developing countries it provides a livelihood for millions of people.

Blockchain technology: Blockchain technology is known particularly in conjunction with cryptocurrencies including Bitcoin. In digital data management, a blockchain is a chain of individual information blocks that can be used to record transaction data that then cannot be modified. The blocks are verified at decentralised level through a computer network. A blockchain can thus be used to document numerous items of information, including evidence, certificates or quality seals that provide information about compliance with labour standards, and environmental and social standards along the upstream and downstream resource supply chain. Data entered can no longer be subsequently modified, providing a high level of security. The information released can be used to determine the origins, trading points and processing of a resource and the products manufactured from it.

CO_2equivalent (CO_2e): CO_2 equivalent (CO_2e) is a unit used to measure the climate impact of different greenhouse gases. The global warming potential of the greenhouse gas actually emitted is converted to a comparable volume of CO_2.

Electrode (cathode/anode): Electrodes are indispensable components in every battery. These are the materials that conduct electrons or electricity. The two electrodes play opposite roles inside a battery. One electrode is positively charged, the other negatively charged. When a battery is in use, it discharges. Electrons flow from one electrode through the electrical device (e.g. an electric engine) to the other electrode.

The conductive electrolyte surrounding the electrodes allows an electron transfer to take place, as charged lithium ions flow from one half cell to the other, where they are deposited. The cathode is the negatively charged electrode. Depending on the battery type it can be made of various metals, such as nickel, cobalt and manganese (NMC). The anode is the positively charged electrode. It is made of lithium-carbon or graphite. When a battery is charged the flow is reversed; the anode becomes the cathode and the cathode becomes the anode.

Electrolytes and conducting salts: Electrolyte is the imprecise overall term used for the medium, generally liquid or gel, that conducts electricity because of the electrically charged atoms or molecules (ions) it contains. Electrolytes can contain various additives. If an electrolyte is not sufficiently conductive, conducting salts can be added to improve this property. This is the case in most lithium-ion batteries.

Large-scale mining (LSM): Industrial or large-scale mining is generally the preserve of major corporations with a large workforce and a high level of mechanisation.

Lithium-iron-phosphate battery (LFP): The LFP battery is one type of lithium-ion battery. Its name comes from the composition of the positive electrode (cathode), which is made of lithium iron phosphate. A graphitic carbon electrode with a lithium backing is used as the anode.

Lithium-ion battery (LIB): Lithium-ion battery is the term used for all batteries that use lithium compounds. The reactive materials contain lithium ions, in both the negative and positive electrodes and in the electrolyte.

Nickel-cobalt-aluminium battery (NCA): The NCA battery is one type of lithium-ion battery. Its name comes from the composition of the positive electrode (cathode), which is made of nickel, cobalt and aluminium. A graphitic carbon electrode with a lithium backing is used as the anode.

Nickel-cobalt-manganese battery (NMC): The NMC battery is one type of lithium-ion battery. Its name comes from the composition of the positive electrode (cathode), which is made of a mix of nickel, manganese and cobalt. The ratio of the metals varies from one manufacturer to another, with the spectrum reaching from a ratio of 1:1:1 to a very much higher nickel content (8:1:1). A graphitic carbon electrode with a lithium backing is used as the anode.

Sustainable Development Goals (SDGs): The 17 Sustainable Development Goals (SDGs) are political goals set out by the United Nations and designed to ensure sustainable development worldwide at economic, social and environmental level. They came into effect on 1 January 2016 and are to be achieved in 15 years (by 2030).

Value creation: This term is used to cover the transformation of existing goods into products with a higher monetary value. Value creation gives us information about the economic effectiveness and productivity of individual processes within a company or indeed a national economy. Since the goal of every economically productive activity is to transform existing goods into goods with a higher monetary value, economic actions seek to maximise value creation.

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