II / 2021 ▪ Study

Sustainability of battery cell production in Europe

How sustainable are batteries and electric mobility really?

Publication of the accompanying research on battery cell production commissioned by the Federal Ministry for Economic Affairs and Energy

in cooperation with

Accompanying Research
BATTERY CELL PRODUCTION

Publisher
VDI/VDE Innovation + Technik GmbH
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Berlin, August 2021

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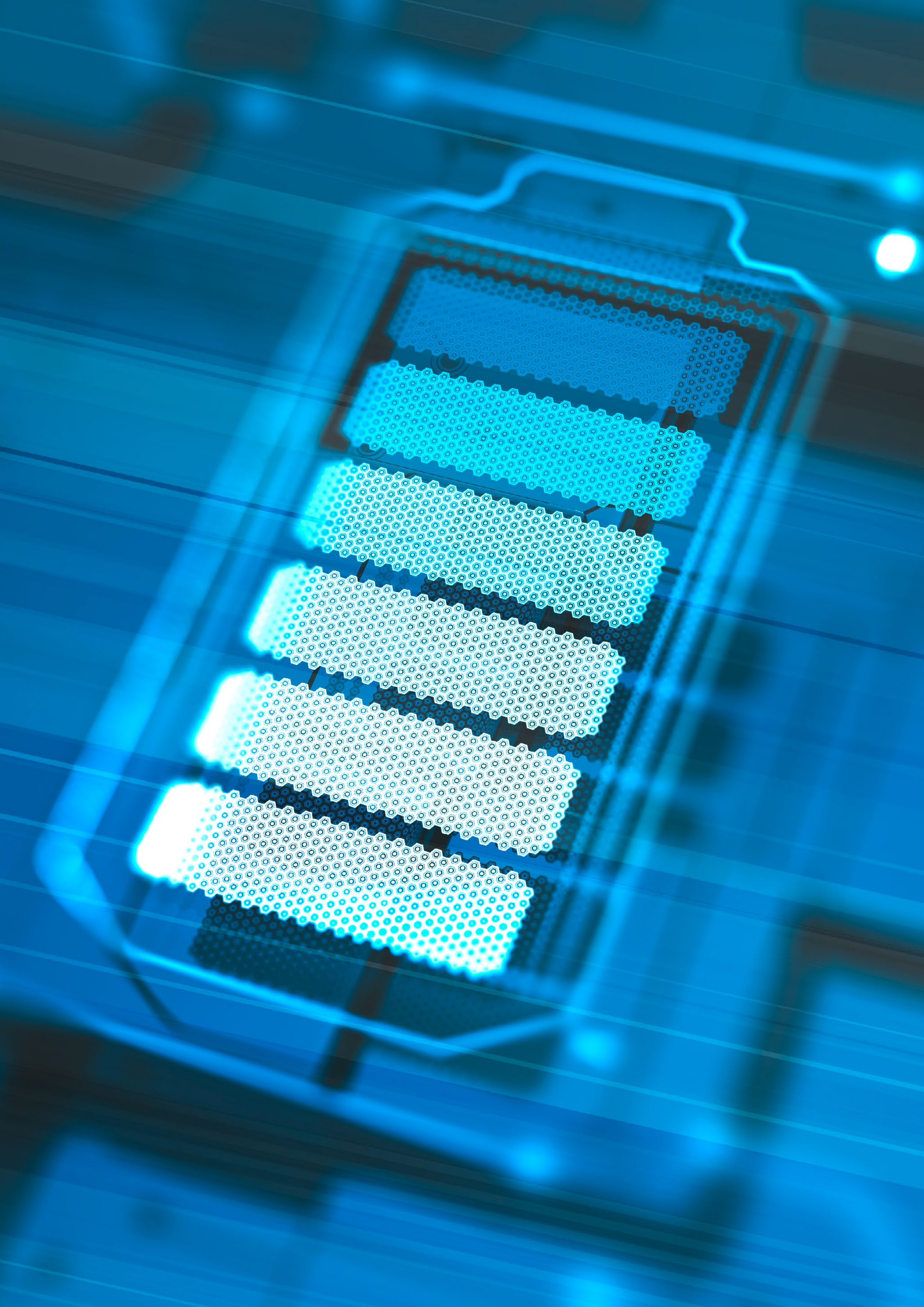


EXECUTIVE SUMMARY

Battery technology is becoming an essential component of sustainable mobility and energy supply. For this purpose, all facets of sustainability must be taken into account when establishing the new European industrial sector of battery cell production. With the aim of producing „green" batteries, a balance of interests must be achieved between the following six sustainability issues: climate protection, industrial policy, circular economy, raw material governance, economic efficiency and employment. This study provides an evidence-based foundation and paves the way for a fact-based debate on the implementation of sustainability criteria in building the battery ecosystem. This analysis leads to the following key statements.

Climate protection: Battery storage is a decisive key technology for the sustainable transformation of the automotive industry as well as the energy supply. The expansion of renewable energies directly leads to a reduction in greenhouse gas emissions in the production and use of batteries. Innovative technologies as well as internationally binding agreements and their regulatory implementation also contribute to this development.

Industrial policy: The strategic promotion of sustainable battery innovations enables the German and European industry to generate competitive advantages. In addition, incentives are provided for cooperation along the entire battery value chain, which leads to the bundling of existing strengths.

Circular economy: The recycling of battery raw materials makes an important contribution to securing the supply of raw materials, to reducing the environmental impact of raw material extraction and to reducing greenhouse gas emissions during raw material processing. Incentives for the collection and recycling of spent batteries accelerate the development of a circular economy.

Raw materials governance: The extraction of raw materials often takes place in countries with low environmental and social standards and new deposits have to be developed for a raw materials supply. Policymakers are shaping the framework conditions for a secure supply of raw materials and for compliance with due diligence obligations in the extraction and processing of raw materials. With the development of a digital product passport for batteries, the industry is paving the way for transparency along the battery supply chain. At the same time, technologies for the substitution of critical raw materials are being developed.

Economic efficiency: The cost parity of battery-electric vehicles and vehicles with combustion engines has already been achieved for the first applications. In particular, this applies to the consideration of the entire life cycle costs of a vehicle. Furthermore, battery-electric vehicles have a high cost reduction potential due to scaling effects and technological innovations in the field of battery cell production.

Employment: The automotive industry is in a transformation phase. Due to productivity gains and a change in demand, there will be a decline in conventional automotive jobs, which can be largely compensated for by consistent investment in battery-cell production and electric mobility. The accompanying reorganisation of value creation will lead to a shift in the demand for labour and thus to a high need for qualifications in the automotive industry.

1 SUSTAINABILITY OF BATTERY CELL PRODUCTION

1.1 The need for sustainable battery cell production

According to a current forecast, the total global demand for batteries for electric vehicles, stationary storage and consumer electronics will increase almost sevenfold in the current decade and rise to around 2,200 gigawatt hours p.a. in 2030.[1] With around 80% of the demand in 2030, the automotive industry is the biggest driver. The transformation of drive technology currently underway for the purpose of reducing greenhouse gas emissions in transport has recently gained significant momentum. Despite the pandemic-related slump in new vehicle registrations worldwide, the sales volume of electric vehicles increased so strongly in Europe in 2020 that their market share in passenger cars rose to 10.5% and even surpassed the number of new registrations in China for the first time.[2]

The market penetration of electric vehicles necessary for the required decarbonisation of the transport sector requires both a far-reaching transformation of the automotive industry and a considerable expansion of battery cell production. To cover the immensely increasing demand for cells in the coming years, production facilities are currently being built and extended globally, but especially in Europe. As a result, global production capacity is expected to increase from the current level of around 320 gigawatt hours per year to up to 3,600 GWh/a by 2030.[3] In order to reduce emissions in the transport sector with the greatest possible impact through the transformation of propulsion technology, sustainable battery production is elementary. Producing batteries responsibly and sustainably means minimising emissions of greenhouse gases and environmentally harmful substances throughout the value chain, eliminating human rights abuses, ensuring safe working conditions, and increasing reuse and recycling.[4]

However, building a circular, responsible and equitable, i.e. sustainable, battery value chain will not be achieved without an active departure from the current development path, but requires coordinated, immediate action by companies, investors and policymakers – in consultation with all stakeholders.[5] Of great importance are the use of responsibly sourced materials, limited use of hazardous substances, a minimum content of recycled material and a minimal carbon footprint, as well as high performance, a long life period and specific labelling of the batteries.[6]

The strong increase in battery demand will lead to a corresponding increase in demand for raw materials, especially cobalt, lithium, nickel and manganese, with significant environmental, social and economic impacts (see chapter 2.2). For traction batteries used in electric vehicles, the EU is expected to need 18 times more lithium in 2030 and as much as 50 times more in 2050 than it did in 2018. In terms of cobalt, demand is expected to be five times higher by 2030 and 15 times higher by 2050 than it is now.[7] The increasing use of batteries will also lead to an increase in the amount of waste (process-related as well as from batteries that have reached the end of their life). The number of recyclable lithium-ion batteries is expected to increase by a factor of 700 between 2020 and 2040.[8]

The production of traction batteries is energy-intensive. Due to this, greenhouse gas (GHG) is emitted in the provision of the thermal and electrical energy required for their production, depending on the power plants and energy sources used. In order for the transformation of the drive technology to lead to the goal of reducing greenhouse gases in transport, it is imperative to minimise the CO_2 footprint of cell production. The lower the emissions from energy supply, the greater the decarbonisation effect of electric mobility.

1 Harrison, 2021

2 Transport & Environment, 2021a

3 VDI/VDE-IT, tbp

4 World Economic Forum, 2019

5 World Economic Forum, 2019

6 European Commission, 2020a

7 European Commission, 2020b

8 European Commission, 2020c

The urgent need for far-reaching and consistent measures against the unsustainable use of natural resources and climate change is not only widely recognised, but is also the subject of many existing agreements and regulations or those currently being drafted. The entry into force of the current draft EU Batteries Regulation will have far-reaching consequences for the production and marketing of batteries. The draft regulation addresses in particular the sustainability of batteries over their entire life cycle, the resilience of the supply chain in the EU and the environmental and social impacts over the entire life cycle of the batteries. Due to its high relevance, a detailed consideration of the proposed EU Batteries Regulation is given in chapter 1.3.

Significant emission reductions in all sectors are essential to limit global warming to well below 2°C and, if possible, to 1.5°C compared to pre-industrial levels (the main goal of the Paris Agreement) and to achieve the goal formulated in the EU Green Deal of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. However, the transport sector is of particular importance with regard to the climate protection efforts being made. In 2018, transport was responsible for the largest share of total EU emissions, accounting for 28% (including aviation and shipping, and 21% excluding the two sub-sectors).[9] Moreover, transport is the only sector where emissions have increased since 1990 – by over 23% in 2018 and by almost 24% according to preliminary data for 2019.[10]

Recent studies conclude that the remaining emissions budget of the EU transport sector would be used up in 11 to 13 years if emissions remain constant with respect to the 2050 climate neutrality target, and that emissions from the transport sector would have to fall to zero as early as 2042-45 in order to meet the 1.5°C target.[11]

In order to achieve the EU climate target, the national climate target in Germany would have to be raised to up to 70% greenhouse gas reduction by 2030 compared to 1990 in the course of so-called burden sharing. Thus the efforts to reduce emissions in all sectors would have to be intensified further. As a result of the German Climate Protection Act of 12 December 2019, which has been judged unconstitutional in parts[12], the German government wants to tighten national climate protection targets. Accordingly, a greenhouse gas reduction of 65% compared to the 1990 emission level is to be achieved by 2030, and greenhouse gas neutrality is to be reached as early as 2045. The current draft law provides for the energy sector to make the largest contribution, with an additional emission reduction of almost 40% compared to the previous climate protection law, but the transport sector is also expected to achieve an increased emission reduction of more than 10% by 2030.[13]

Electric mobility can make the key contribution to achieving climate neutrality of the transport sector in Germany in 2045, as a recent study[14] predicts: By increasing the number of e-cars (incl. plug-in hybrids) to 14 million vehicles, using electrically powered trucks (battery-electric, overhead lines and fuel cells) for almost a third of road freight transport, increasing rail freight transport and significantly increasing public transport, cycling and walking in the modal split, CO_2 emissions from the transport sector could be reduced from 162 million tonnes in 2018 to 89 million tonnes, i.e. by around 45% in 2030. By almost completely replacing all existing vehicles with internal combustion engines with electric cars, including no new registrations of passenger cars with internal combustion engines from 2032 onwards and an almost complete switch to electrically powered trucks, buses and trains, as well as the use of exclusively electricity-based fuels in air and sea transport, especially after 2035, a greenhouse gas-neutral transport sector could be achieved in Germany in 2045.[15]

To accelerate the necessary market penetration of electric vehicles, more investments must be made along the entire

9 Transport & Environment, 2020a

10 European Environment Agency, 2020a

11 Plötz et al., 2021

12 BVerfG, 2021

13 Die Bundesregierung, 2021a

14 Prognos, Öko-Institut, Wuppertal-Institut, 2021

15 Prognos, Öko-Institut, Wuppertal-Institut, 2021

value chain as well as in the application infrastructure (e.g. charging infrastructure). In addition, batteries must become more affordable for end users through lower production costs, higher utilisation and improved business models.[16] These challenges have been recognised and accepted by both politics and business. On a political level, the European Battery Alliance (EBA) has set the target that one third of the world market demand for batteries for electric vehicles will be manufactured, sold and exported in Europe by 2030. The EBA estimates the market potential for automotive batteries produced in Europe to be up to 250 billion euros already by the mid-2020s.[17] Motivated by political support in the form of government subsidies (cf. chapter 2.2.2) and correspondingly optimistic forecasts of market demand for electric vehicles (cf. chapter 2.1), numerous so-called gigafactories are currently being built or at least planned in Europe by various domestic and foreign battery manufacturers, which together will reach an annual production capacity of up to 960 GWh in 2030.[18] This dynamic gives rise to both a need to regulate battery cell production and the opportunity to implement correspondingly far-reaching measures with the aim of increasing battery sustainability even before many production facilities are completed.

In the following, this publication provides an overview of the status quo and the perspectives of the different aspects of sustainable battery cell production in Europe. Based on theses, the relevant sustainability topics of climate protection (2.1), industrial policy (2.2), circular economy (2.3), raw material governance (2.4), economic efficiency (2.5) and employment (2.6) are discussed. In addition to the current debate, current scientific findings are discussed and contrasted in particular.

1.2 The concept of sustainability in the context of battery cell production

The complexity of the term sustainability makes a context-related definition necessary. The understanding of the concept of sustainability on which this study is based is fundamentally and contextually oriented towards the European Commission’s definition of sustainable batteries. These are **“[...] produced with the lowest possible environmental impact, using materials that have been obtained in full respect of social and ecological standards, long lasting and safe and that can be repaired or reused and repurposed”.**[19]

In this study, sustainability is discussed for the following three levels:

- Ecological sustainability: By definition, ecological sustainability is a principle according to which no more may be consumed than can grow back, regenerate and be made available again in future.
- Economic sustainability: The goal of economic sustainability is to form an economic system that is functional in the long run. A high level of employment, price stability and external economic balance are considered to be the three basic goals that must be achieved in order to maintain this system in the long term.
- Social sustainability: Social sustainability describes the conscious organisation of social and cultural systems, especially with regard to human dignity and labour and human rights. Within companies, this can be seen, for example, in the impact of social action in dealing with employees or in relations with interest groups.

In general, in this study, the term “sustainability” is understood to mean sustainable development, which refers

both to the three guiding strategies

- *Sufficiency* (reduction of production and consumption),
- *Efficiency* (more productive use of material and energy), and
- *Consistency* (nature-friendly material cycles, recycling, waste avoidance),

as well as to the political objectives of the United Nations (UN) to ensure sustainable development worldwide on an economic, social and ecological level. These goals were

16 World Economic Forum, 2019

17 BMWi, 2021a

18 VDI/VDE-IT, tbp

19 European Commission, 2020b

3 GOOD HEALTH AND WELL-BEING

By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

6 CLEAN WATER AND SANITATION

By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

7 AFFORDABLE AND CLEAN ENERGY

By 2030, ensure universal access to affordable, reliable and modern energy services.

By 2030, double the global rate of improvement in energy efficiency.

8 DECENT WORK AND ECONOMIC GROWTH

Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services.

Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-YEAR FRAMEWORK OF PROGRAMMES ON SUSTAINABLE CONSUMPTION AND PRODUCTION, with developed countries taking the lead.

Take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labour, including recruitment and use of child soldiers, and by 2025 end child labour in all its forms.

Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.

Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending.

Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities.

11 SUSTAINABLE CITIES AND COMMUNITIES

By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

By 2030, achieve the sustainable management and efficient use of natural resources.

By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle.

13 CLIMATE ACTION

Integrate climate change measures into national policies, strategies and planning.

Figure 1: Selected SDGs for sustainable development and targets with high relevance for battery cell production. Own representation.

formulated at the 2015 World Summit on Sustainable Development in the framework of the so-called "2030 Agenda for Sustainable Development" in the form of **17 Sustainable Development Goals (SDGs)**.

However, as not all 17 SDGs or their 231 sub-goals are relevant to the consideration of battery sustainability, a contextual extract is considered in this study. Figure 1 lists this extract and shows which Sustainable Development Goals and sub-goals are considered in the thesis-based discussions of the relevant sustainability topics of this study.

1.3 Sustainability in the proposal for a new EU Batteries Regulation

On 20 December 2020, the European Commission proposed a modernisation of EU legislation on batteries. The submitted proposal for a Regulation on batteries and waste batteries is an integral part of the European Green Deal and the first initiative of the European Commission on the Circular Economy Action Plan. Accordingly, the draft Regulation is characterised by sustainability aspects, through which, for example, the Sustainable Development Goals (SDGs) from the 2030 Agenda are also partially realised. Thus, the draft addresses the social, economic and ecological aspects in connection with batteries, but also provides for a regulation of access to the EU internal market. This means not only all batteries produced in the EU must meet the envisaged sustainability requirements, but also all batteries from third countries that are placed on the market in the EU. Due to the size of the European market, this regulation will also have a correspondingly large relevance for countries outside the EU.

Since battery technology is a so-called general purpose technology that is not only used in the automotive industry, but has positive external effects (spill-overs) on other sectors,[20] battery cells have become the key technology of the energy transition with enormous strategic importance for Europe. This has been accompanied by technological developments, dynamic markets and changing socio-economic conditions. In order to adequately accompany this dynamic development – especially with regard to sustainability aspects – the current Batteries Directive, which has existed since 2006, or its national implementation is no longer sufficient. The proposed Regulation on batteries and waste batteries fundamentally modernises the provisions within the legal framework of a regulation that is directly applicable in all member states after entry into force and does not require transposition into national law. The goal is harmonised, sustainable and pioneering regulations that ensure more legal certainty for all stakeholders, create incentives for investments in the EU and strengthen innovation.

The Proposal for a Regulation on batteries and waste batteries is strongly oriented towards sustainability principles, although the ecological, economic and social aspects are not taken into account to the same extent. For example, social aspects are strongly taken into account in measures for the extraction of raw materials and hardly at all in other phases of the value chain.

In general, the following objectives are named in the proposal for a Regulation on batteries and waste batteries:

- Strengthen the **sustainability of batteries throughout their entire life cycle** by ensuring minimum sustainability requirements for batteries in the EU internal market,
- Increase the **resilience of the supply chain in the EU** by creating a closed material cycle, and
- Minimise the **environmental and social impact** over the lifetime of the batteries.

In order to achieve these overarching goals, the proposal for a Regulation on batteries and waste batteries defines the following specific objectives:

Strengthen sustainability:
- Promote the production and marketing of high quality and high performance batteries on the EU internal market,
- Develop and exploit the EU's potential in the use of primary and secondary battery raw materials and ensure that they are sourced efficiently and sustainably,
- Ensuring functioning markets for secondary raw materials and establishing the associated industrial processes,

20 Hagedorn et al., 2019

- Promoting innovation and the development and application of technological expertise in the EU.

Increase resilience:
- Reducing the EU's dependence on imports of strategically important materials,
- Ensure adequate collection and recycling of all spent batteries.

Minimise environmental and social impacts:
- Contribution to responsible sourcing of raw materials,
- Efficient use of raw materials and recyclates,
- Reduction of greenhouse gas emissions over the entire life cycle of batteries,
- Reducing risks to human health and the quality of the environment, and improving the social conditions of local communities.

Accordingly, the proposal for a Regulation on batteries and waste batteries shows more consensus with current EU approaches to the sustainable management of materials and waste, which focus on optimising products and production processes. Thus, the draft is a building block in the development of an EU framework for the whole life cycle of batteries, including harmonised and more ambitious rules for batteries, components, spent batteries and recyclates. The clear common rules will ensure and promote the functioning and sustainability of the EU internal market for batteries as well as the market for the necessary primary and secondary materials.

2 THESES ON SUSTAINABLE BATTERY CELL PRODUCTION

2.1 Climate protection

2.1.1 Electric mobility makes a significant contribution to reducing emissions in the transport sector

- Expansion of **renewable energies**. The energy supply for both battery (cell) production and vehicle operation are crucial for the GHG balance. The lower the emissions of the energy provided, the greater the **decarbonisation effect** of electric mobility.
- The goal is the establishment of (battery cell) production capacities in Europe. Due to the fact that currently the **energy supply in Europe** is significantly **lower in emissions** than in China, the CO_2 footprint of cells produced in Europe is lower.
- The capacity of a battery is decisive. The larger the battery capacity, the higher its **production-related CO_2 footprint** and, consequently, the mileage at which battery-electric vehicles have a more favourable emissions balance than vehicles with combustion engines.

The production of battery-electric vehicles currently emits more greenhouse gases than the production of comparable vehicles with combustion engines

The production of traction batteries is very energy-intensive. Depending on the power plants and energy sources used, greenhouse gas (GHG) is emitted in the provision of the necessary thermal and electrical energy. In studies[21] [22] [23] on powertrain-specific production emissions, the glider (a common term in life cycle analysis for the residual vehicle without powertrain) is often equated with identical vehicle classes due to the need to compare powertrain technologies, and only the specific powertrain is considered in a differentiated manner. The total emission of the vehicle production (cradle-to-gate) consequently results from the amount of GHG released during the production of the glider and the production-related emissions of the specific components such as exhaust system, clutch and tank system for vehicles with combustion engine (ICEV), the fuel cell for vehicles with fuel cell (FCEV) or the traction battery for battery-electric vehicles (BEV). Due to the different energy intensity of the drive technology-specific manufacturing processes, more CO_2-eq is emitted in the production of vehicles with fuel cells (FCEV) than in comparable ICEVs and less than in comparable BEVs, given an identical energy supply.[24] Without taking battery production into account, the production-related emissions of BEVs are somewhat lower than those of comparable ICEVs. The fact that the emissions balance at the time of vehicle delivery (gate) is nevertheless up to a factor of 2 higher for BEVs in some studies[25], is due to the energy-intensive battery production.

Consequently, the emissions from the energy supply for the battery production process have an enormous impact on the GHG balance of BEVs. Based on primary raw materials, Emilsson & Dahllöf put the emissions from the production of nickel-manganese-cobalt-based (NMC 111) lithium-ion batteries at 61 - 106 kg CO_2-eq per kWh battery energy.[26] In a study, Koch et al. cite manufacturing-related emissions from batteries of identical technology of about 180 kg CO_2-eq or 120 kg CO_2-eq per kWh of battery energy – depending on whether the battery is produced in China or Europe.[27] Both the energy efficiency of the manufacturing processes and the power plant-dependent energy supply influence the GHG emissions, so that the emissions from battery production are only given as value ranges and, according to the study by Koch et al., are currently one third lower in battery production in Europe than in China. Depending on the assumptions used in the analyses, emissions range from 61 to 180 kg per kilowatt-hour of storage capacity and thus differ by up to a factor of 3 (see Figure 2). For an average 50 kWh battery, this means an absolute difference of just under 6 metric tons of CO_2-eq

21 Transport & Environment, 2017

22 Sternberg et al., 2019

23 Koch et al., 2020

24 Sternberg et al., 2019

25 Koch et al., 2020

26 Emilsson & Dahllöf, 2019

27 Koch et al., 2020

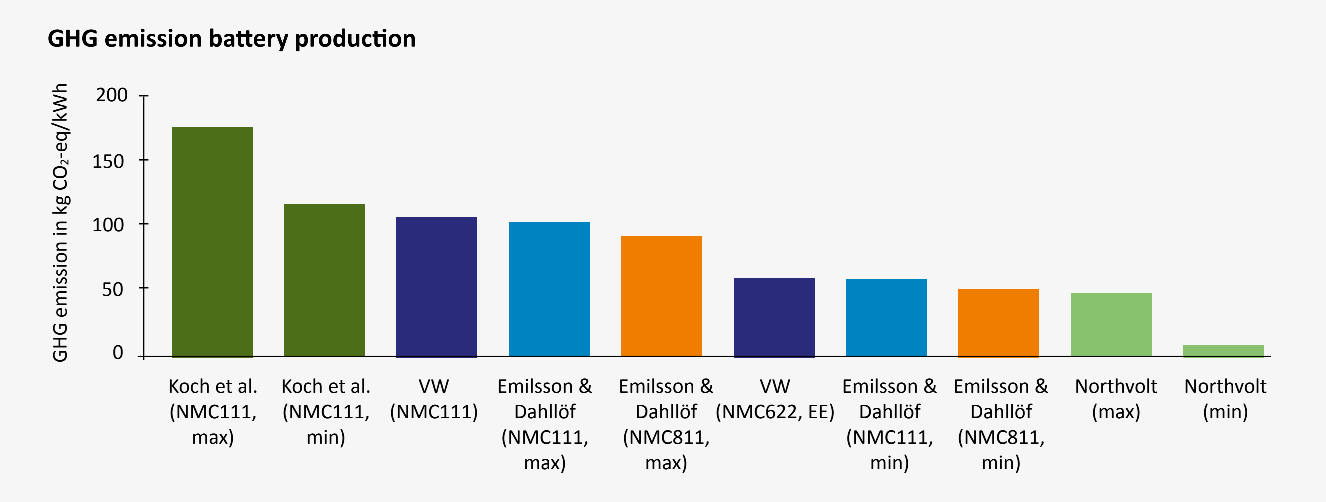


Figure 2: GHG emissions of battery production. The areas represent the emissions of the production of different NMC technologies standardised to the storage capacity. Own representation

between the two extreme values, which is roughly equivalent to the emissions from the production of the glider.

In addition to the production location and the GHG emissions of the energy supply that depend on it, the cell technology in particular influences the emissions balance. Emilsson & Dahllöf put the reduction in GHG emissions for the production of cells with current technology (NMC 811) at 14% compared to NMC 111 due to their higher energy density. As a result of the switch to NMC 622 and the agreement with the battery cell suppliers to use electricity from renewable sources, VW indicates a near halving of the specific CO_2 footprint of the batteries used from 110 to 62 kg CO_2-eq/kWh.[28] By its own account, Northvolt says it aims to achieve production-related emissions of between 10 and 50 kg CO_2-eq per kWh in the medium term through material recycling and innovative sourcing strategies.

Figure 2 illustrates the enormous range of manufacturing-related emissions standardised to the stored capacity of battery production. This is due to the emissions of the energy supply, the energy intensity of the production process and the energy density of the respective battery technology. Based on the production of a battery with a capacity of 50 kWh, between 500 and 6,000 kg CO_2-eq are emitted, depending on the battery technology, manufacturing process and energy supply. This exemplary consideration of absolute production emissions not only highlights their wide range, but also illustrates the influence of battery capacity on the GHG balance of BEVs. The greater the storage capacity of the battery and thus the range of the BEV, the greater the difference to comparable ICEVs – especially if battery technologies with high energy density are not used.

Increased greenhouse gas emissions in the transformation phase

These high production-related GHG emissions are equally incurred for batteries that originate from pre-series productions, prototype vehicles, recalls or faulty production and are thus recycled immediately after production or at least well before their technological end of life. As reported by Handelsblatt, the ramp-up of electric mobility currently entails hundreds of tons of batteries that are not reused but recycled well before they reach the end of their life (cf. chapter 2.3).[i] Consequently, during the transformation process of the automotive industry and the establishment and expansion of battery cell production, more GHG will initially be emitted.

i Scholz, 2021

28 Volkswagen, 2020a

The higher demand for energy in the manufacturing processes for vehicles with alternative powertrains, and in particular those of battery production, reinforce the urgent need to implement production in an energy-efficient manner and to provide the required energy with low GHG emissions. As recent studies show, GHG emissions from battery manufacturing can vary by up to a factor of 3. Due to the current location-related differences in energy provision, the production of battery cells at European locations instead of production in China results in an immediate and significant reduction of GHG emissions. China is also focusing on an expansion of renewable energies, which will lead to lower production-related GHG emissions in the future. However, last year's progress and also the future targets on the part of the European energy industry are clearer and more ambitious (see chapter 2.1.2). As a result, Europe already offers advantages in terms of production-related GHG emissions and thus also for the GHG balance over the entire life cycle of electric vehicles, and will further expand these advantages in the coming years.

The operation of battery-electric vehicles is more climate-friendly than that of vehicles with fuel cells or internal combustion engines

Even the energy supply (well-to-tank), i.e. the provision of fuel at the gas pump or electrical energy at the charging station, is energy-intensive. The greenhouse gas emissions from the extraction and processing of crude oil amount to around a quarter of the emissions from vehicle operation (26% of tank-to-wheel emissions for gasoline and 28% for diesel).[29 30] Converted to the energy content of gasoline or diesel, the well-to-tank emissions are around 73 and 75 g CO_2-eq per kWh, respectively. Emissions from electricity generation are highly dependent on the power plants and energy sources used. The average GHG emission from electricity generation in 2020 was 413 g CO_2-eq per kilowatt-hour in Germany and 319 g CO_2-eq/kWh in the EU-27.[31] The generation of hydrogen from electricity (power-to-gas) results in corresponding emissions from electricity generation, but the hydrogen must then be converted into a transportable state, which is energy-intensive (cf. Figure 3). The emissions caused by transporting the fuel to the filling station or the electricity to the charging station via the corresponding tanker vehicles or power losses are not taken into account here.

An exemplary consideration of the operational emissions (well-to-wheel) using the example of a VW Golf VII[i] shows that a model with a 96 kW gasoline engine emits about 17.6 kg CO_2-eq per 100 km and a battery-electric model (35.8 kWh battery capacity) with 100 kW power emits about 7.5 kg CO_2-eq per 100 km (GHG emission of electricity generation in Germany 2020).

	Consumption per 100 km	Emissions energy supply (w-t) CO_2-eq (energy for 100 km)	Emissions operation (t-w) CO_2-eq per 100 km	Total emissions (w-t-w) CO_2-eq per 100 km
Golf VII	5.9 l (Super)	3,623 g	13,983 g	17,606 g
Golf VII e	18.2 kWh[ii]	7,517 g	-	7,517 g

i ADAC, 2021a und 2021b
ii Combined consumption according to WLTP. Charging losses are included in the ADAC test. Source: ADAC, 2021c

29 Knobloch et al., 2020

30 Gasoline and diesel production from crude oil emit about 614 and 735 g CO_2-eq per liter, respectively. Ibid.

31 Transport & Environment, 2020b

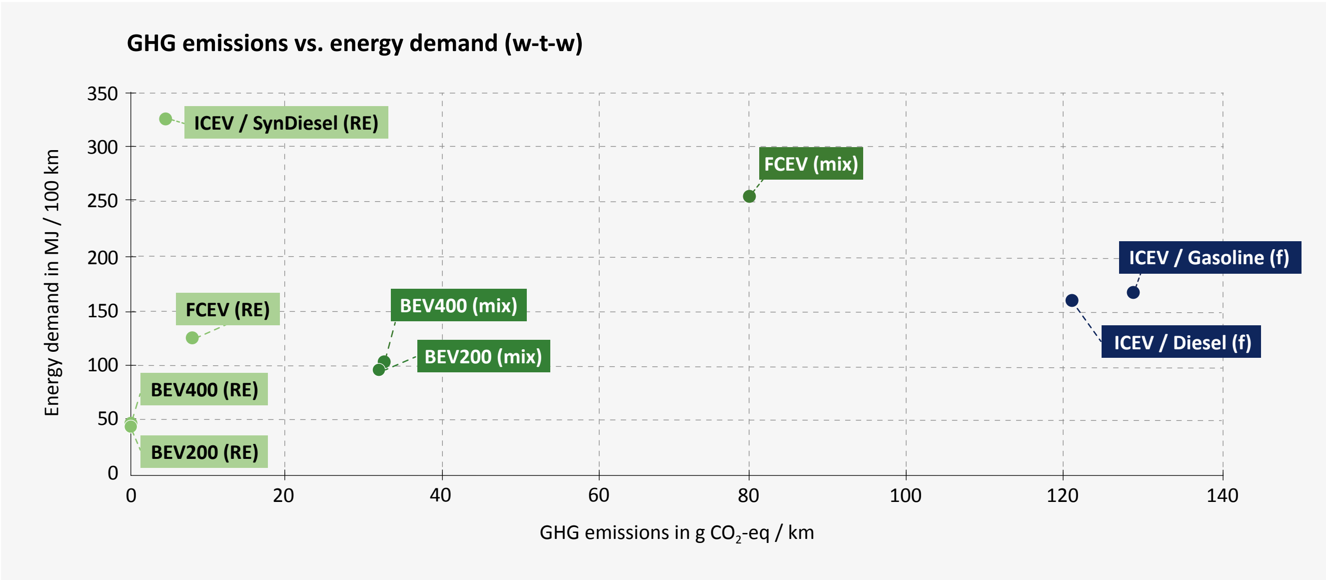


Figure 3: Well-to-wheel analysis: GHG emissions and energy demand of different propulsion technologies or energy sources (f=fossil; mix=EU electricity mix; RE=renewable energy). According to JEC Well-To-Wheels report v5.

Through the operation of the vehicles (tank-to-wheel), i.e. the conversion of chemical or electrochemical energy into kinetic energy, both greenhouse gases and air pollutants are released by vehicles with internal combustion engines, in contrast to the locally emission-free BEVs and FCEVs. On average, 143 g CO_2-eq, 0.95 g carbon monoxide, 0.14 g volatile hydrocarbons, 0.39 g nitrogen oxides and 0.005 g particulates[32] were emitted per passenger kilometer in passenger cars in Germany in 2020.[33] Despite lower specific emissions as a result of stricter emissions regulations for newly registered passenger cars and improved quality of the fuel placed on the market, the total emissions of the various air pollutants from passenger car traffic have developed inhomogeneously between 1995 and 2018. While nitrogen oxide emissions decreased by 33% and particulate matter emissions by nearly 80%, total carbon dioxide emissions increased by 3.7%.[34] Consequently, there are major differences between the drive technologies during operation. While the use of BEVs and FCEVs emits greenhouse gases and air pollutants only indirectly due to the current electricity mix, ICEVs also emit greenhouse gases and air pollutants directly during operation.

Figure 3 shows the energy demand (well-to-wheel) of various drive technologies per 100 km of travel distance as a function of the energy source, plotted against their GHG emissions. It can be clearly seen that ICEVs powered by fossil fuels have the highest GHG emissions in this comparison, but are in the middle in terms of energy demand. Significantly lower GHG emissions are emitted by ICEVs powered by synthetic diesel. However, in this case, the energy demand is the highest due to the energy-intensive manufacturing process of the fuel. At comparable emission levels are BEVs and FCEVs that run on electricity from renewable sources or hydrogen generated from them. Here, however, the high energy input for hydrogen production and conversion to a transportable state becomes clear, as a result of which the operation of FCEVs requires more than twice as much energy as that of BEVs.

A comparative study by PricewaterhouseCoopers on the energy efficiency of drive technologies (well-to-wheel) that use renewable energies and no fossil fuels shows that the operation of battery-electric vehicles is the most favorable in terms of energy. Based on climate-neutral electrical energy

32 Without consideration of tire or road abrasion.

33 Umweltbundesamt, 2021a

34 Umweltbundesamt, 2020

from renewable sources (sun, wind), its conversion into 1 kWh of mechanical energy (motion) requires 1.4 kWh for BEVs, 2.8 kWh for FCEVs and 8.7 kWh for ICEVs powered by synthetic fuels.[35] Vehicles with these drive technologies emit significantly less net GHG during operation than conventionally powered vehicles and thus contribute enormously to the decarbonisation of transport. However, the difference in energy efficiency becomes particularly clear when considering the respective electricity requirements for the hypothetical case that the mileage of all passenger cars in Germany in 2018 is achieved with only one drive technology. If the mileage was achieved with BEVs, about 90 TWh of electrical energy would be required for their operation, and thus about 40% of the electricity generated in Germany in that year would come from renewable energies. If the mileage were to be provided exclusively by FCEVs, about 100% of the electricity generated in Germany in 2018 from renewable energies would be required to supply “green hydrogen”.

Depending on their mileage, battery-electric vehicles are already more climate-friendly than vehicles with fuel cells or internal combustion engines

Taking into account the production and operational GHG emissions, which depend significantly on the framework conditions such as production location and battery capacity, a battery-electric vehicle currently has higher emissions at the time of delivery and lower emissions during operation than a similar vehicle powered by an internal combustion engine. Provided that the chemical or electrochemical energy for traction comes from renewable energy sources, BEVs are significantly more energy efficient than the other propulsion technologies.

Depending on the emissions difference after production and the emissions of the energy industry that generates the electrical energy for charging, there is an overall emissions parity after a certain mileage. Before this mileage is reached, the emissions balance for BEVs is worse. If the vehicle is used beyond this mileage, the balance for BEVs is better. This decisive mileage depends on various factors and is all the lower the lower the emissions from the energy supply for both production and vehicle operation, the smaller the storage capacity of the battery and the higher the energy density of the battery. For the exemplary comparison of a VW Golf VII with Otto engine and one with battery-electric drive (see info box on p. 12), the decisive mileage is around 60,000 km in the tank-to-wheel consideration and just under 50,000 km in the well-to-tank consideration.[36] Using the GHG emission data of the current European electricity mix as well as those released during the production of current NMC 622 cells according to VW, the mileage is reduced to about 25,000 and just under 20,000 km, respectively.

In the coming years, this minimum mileage, at which BEVs are more climate-friendly than alternative powertrains, will become ever smaller. On the one hand, the energy industry has been able to significantly reduce emissions from electricity production in recent years through a strong expansion of renewable energies and will continue this development in the coming years due to regulations (see chapter 2.1.2). On the other hand, the development and expansion of production capacities for battery cells in Europe and the increase in the energy density of traction batteries are leading to ever smaller emission differences between BEVs and ICEVs at the time of vehicle delivery. This is counteracted by both the trend towards ever higher battery capacities and an increase in the efficiency of combustion engines. The latter, however, only leads to a marginal increase in the decisive mileage of BEVs due to the already very high level of technical maturity.

35 Bollmann et al., 2017

36 The calculation is based on the GHG emission of electricity generation in 2020 in Germany of 413 g CO_2-eq per kilowatt hour and the GHG emission of 110 kg CO_2-eq per kilowatt hour of battery capacity stated by VW for the production of NMC111 batteries. The GHG emission of the production of the glider was assumed to be 8.0 t CO_2-eq for the Otto engine model and 8.1 t CO_2-eq for the battery-electric model.

2.1.2 New climate policy regulations and instruments increase the pressure for action to drive forward the decarbonisation of the transport sector in the EU

- **Decarbonisation** of the transport sector is urgent, as it is the only sector where emissions have increased since 1990.
- **Climate policy regulations** and **instruments** set clear targets for decarbonising the transport sector, create the necessary framework conditions and provide additional incentives.
- The new **EU Batteries Regulation** will ensure transparency and fair competition for sustainable batteries in Europe.

Greenhouse gas emissions in the transport sector are too high

DOverall greenhouse gas emissions in the EU-27 fell by 24% between 1990 and 2019, exceeding the target of a 20% reduction from 1990 levels by 2020 ahead of schedule.[37] However, transport is the only sector where emissions have increased significantly over the same period (+23.7%).[38]

Greenhouse gas emissions in the transport sector in Germany in 2019[39] were also above the 1990 level at 165.5 million t CO_2-eq compared to 164.9 million t CO_2-eq.[40] The main reasons for the persistently high CO_2 emissions in the transport sector are the dominance of fossil fuels, the increase in mileage, heavier vehicle models in passenger transport and the rising number of cars and flights in passenger and freight transport.[41] In Germany, motorised road transport is responsible for 94% of greenhouse gas emissions in the transport sector. Passenger cars account for about 59% and trucks and other commercial vehicles for 35%.

Climate agreement and national climate protection goal set clear targets

In April 2021, the EU member states agreed with the EU Parliament to raise the EU climate goal for 2030 from a minimum reduction of emissions of 40% compared to 1990 to 55%. CO_2 emissions in the transport sector must therefore be reduced by an average of 37.5% per kilometre by 2030 for passenger cars sold in the EU and by an average of 31% per kilometre for new trucks compared to 2021 levels.[42] With the adoption of Regulation (EU) 2019/631, the CO_2 fleet limit applicable until 2019, i.e. the upper limit for the average CO_2 emissions of all vehicles registered in the EU in a year, has been significantly reduced from 130 to 95 gCO2/km in 2020.

According to the national climate protection goal, emissions in the transport sector in Germany are to be reduced by 40 to 42% by 2030 compared to 1990. In absolute terms, this means a reduction in emissions from 164 to 98 to 95 million tonnes of CO_2.[43] As a result of the German Climate Protection Act, which has been judged unconstitutional, the German government wants to tighten climate protection goals.[44] Accordingly, a greenhouse gas reduction of 65% (compared to the emission level of 1990) is to be achieved by 2030 and greenhouse gas neutrality is to be reached as early as 2045. The current draft law provides for the energy sector to make the largest contribution, but the transport sector is also expected to achieve a more than 10% increase in emission reductions by 2030. In light of the almost identical transport-related emissions in 1990 and 2019, the significant emission reduction is to be achieved completely in the current decade.

37 European Environment Agency, 2020a

38 European Environment Agency, 2020b

39 Update: 145.6 million t CO_2eq in 2020 and thus 19 million tonnes lower than in the previous year (minus 11.4%) – and thus also below the annual emission quantity of 150 million tonnes CO_2 for 2020 specified in the Federal Climate Protection Act. However, the main part of this reduction is pandemic-related and due to less driving during the first lockdown, especially on long distance trips. In the view of the authors, this is a unique and non-permanent development that is not taken into account here.

40 Umweltbundesamt, 2021b

41 BMU, 2020

42 Regulation (EU) 2019/631

43 Die Bundesregierung, 2021b

44 Die Bundesregierung, 2021a

Regulatory stimulation of electric mobility leads to decarbonisation of the transport sector

The emissions balance of battery-electric vehicles is, as explained in chapter 2.1.1, lower than that of comparable vehicles with combustion engines after a certain mileage. With regard to the use of renewable energies, BEVs also have by far the highest efficiency. Consequently, BEVs that are used instead of ICEVs and whose mileage exceeds the limit value contribute directly to the decarbonisation of the transport sector.

After initially very low registration figures, the market ramp-up of electric vehicles has recently gained significant momentum. The effect of the EU fleet limit on the registration numbers of battery-electric vehicles in 2020 is clearly visible. The announcement of high fines for non-compliance with EU-wide CO_2 emission goals for vehicle fleets gave a boost to both the supply and sales of electric cars (battery-electric, BEV and plug-in hybrid electric, PHEV). Despite the COVID-19 crisis, which led to a 25% drop in car sales in Europe in 2020, the total number of electric cars sold in Europe more than doubled over the same period, rising from around half a million vehicles in 2019 to more than 1.3 million in 2020 (more than one million in the EU-27).[45] As a result, the Chinese EV market was surpassed by Europe for the first time.[46]

As a result of the recent significant increase in the market share of electrically powered vehicles, many will reach the minimum mileage in the medium term and thus contribute to the decarbonisation of the transport sector. The expansion of renewable energies and the associated reduction in emissions from electricity generation will also further increase the positive GHG effect of electric mobility in the medium term.

Energy-economic conditions for alternative powertrains are in place

In both the EU-27 and Germany, GHG emissions from the energy sector were reduced by over 30% in 2020 compared to 1990. This is due to the reduction in the use of high-emitting energy sources as well as the expansion of renewable energies and has a direct impact on the GHG emission reduction potential of alternatively powered vehicles. This is because the dependency of BEV emissions on low-emission energy provision and thus on the use of renewable energies both in vehicle and cell production and in charging the traction batteries is immense (cf. chapter 2.1.1). The fewer GHGs are emitted in the provision of the necessary energy, the greater the contribution of BEVs to the decarbonisation of the transport sector.

The reduction in the use of high-emitting energy sources is due to the central European climate protection instrument, the European Emissions Trading Scheme (EU ETS), which was introduced in 2005 to implement the Kyoto international climate protection agreement. The EU ETS records the emissions of around 11,000 installations in the energy sector and energy-intensive industry across Europe, which together account for around 40% of GHGs in Europe. Within a continuously decreasing emissions cap, emission allowances can be freely traded on the market. This creates a prospectively rising price for the emission of greenhouse gases, which creates incentives for the participating companies to reduce their GHG emissions.

The expansion of renewable energies continues. In 2019, 19.7% of the final energy demand in the EU-27 was covered by renewables.[47] In Germany, the share was 17.4% in 2019, with electricity from renewable energies accounting for 42% of gross electricity demand. The Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz - EEG 2021) sets the target for Germany to increase the share of electricity generated from renewable energies in gross electricity demand to 65% in 2030.[48] The already high share of renewable energies, which will continue to increase in the future, is a necessary prerequisite for emission reductions in the transport sector to have the greatest possible impact through the transformation of propulsion technology.

45 Transport & Environment, 2020a

46 Transport & Environment, 2021a

47 Eurostat, 2021

48 EEG, 2021

CO_2 pricing favours low-emission mobility

A new pillar in the German government's climate protection programme is the CO_2 pricing in the transport sector, which came into force at the beginning of 2021.[49] In order to further reduce emissions in transport – in analogy to European emissions trading in the energy sector and energy-intensive industry – the national emissions trading system (nationales Emissionshandelssystem – nEHS) provides an incentive to reduce transport-related emissions in Germany. Through the nEHS, certificates are sold to companies that put heating and motor fuels on the market in Germany. From now on, companies must purchase a certificate as a pollution right for every tonne of CO_2 that the substances will cause in consumption. The cost for this has been 25 EUR since January 2021 and will gradually rise to 55 EUR in 2025. For 2026, a price corridor of at least 55 EUR and at most 65 EUR is envisaged. As a result, the prices for gasoline and diesel will continue to rise immediately and in the years to come, thus indirectly favouring low-emission forms of mobility.

Declaring the footprint of cell production creates transparency and fair competition

The proposal for a Regulation on batteries and waste batteries (COM/2020/798 final)[50] introduces, among other things, progressively increasing requirements for batteries placed on the EU market in the future, aiming at minimising the carbon footprint over the entire life cycle of batteries. In December 2020, the European Commission published the proposal for a Regulation on batteries and waste batteries (see chapter 1.3), which is the first concrete legislative proposal to be made as part of the implementation of the new Circular Economy Action Plan[51] of March 2020, which in turn is an essential building block of the European Green Deal.[52]

According to the proposal for a Regulation on batteries and waste batteries, an information obligation is planned first. Also, the technical documentation for rechargeable industrial batteries and traction batteries with an energy of more than 2 kWh placed on the EU market shall be accompanied by a carbon footprint statement in order to ensure transparency regarding emissions from battery production. In order to shift the EU market towards lower CO_2 batteries in the medium term – regardless of where they are produced – the proposal for a Regulation on batteries and waste batteries intends a gradual and cumulative increase in the requirements for the CO_2 footprint. A performance class-specific maximum emission limit is planned, which may not be exceeded with regard to placing on the market in the EU market.

The transparent disclosure of manufacturing emissions and the setting of upper limits for placing on the market creates a fair competitive environment for sustainably produced "green" batteries. The CO_2 emissions avoided during the life cycle of batteries as a result of these requirements also contribute to the EU's goal of climate neutrality by 2050.

Electrification of vehicles alone is not enough to achieve medium-term climate protection targets in the transport sector

The current European fleet emission standard, even in its more ambitious, revised form, (cf. Section „Climate agreement and national climate protection goal set clear targets") is not sufficient to achieve the German climate protection targets for the transport sector, as current calculations show.[53] Their analysis of the short- and medium-term reduction potential leads to the conclusion that even a very ambitious scenario (95% newly registered electric vehicles in 2030) only leads to a reduction of GHG emissions by 27% by 2030 compared to 2019 or 1990 (the current national climate protection goal indicates a reduction of 40 to 42%). This is not least due to the existing vehicles, which will still be on the market in 2030 because of their average lifespan. Also according to the NPM reference scenario, emissions in the transport sector will decrease from about 165 to 150 milion t CO_2-eq. by 2030. According to the NPM, this leaves a reduction gap of an additional 52 to 55 million t CO_2-eq for achieving the current climate protection target in transport.[54] In the long term,

49 Die Bundesregierung, 2019

50 European Commission, 2020d

51 European Commission, 2020e

52 European Commission, 2019b

53 Rudolph & Jochem, 2021

54 NPM, 2019

i.e. by 2050, many analysts expect a strong reduction in emissions, but in a recent study by Transport & Environment, the medium-term reduction effect is assessed as too low and, with a view to achieving the climate protection goals, it is concluded that the transformation should already be further accelerated now.[55] On the other hand, however, there are warnings from the industry. According to the VDA, a tightening of the EU climate targets in the Corona crisis, for example, increases the pressure on the automotive industry, which is in a process of transformation.[56]

2.2 Industrial policy

2.2.1 Cooperation and political governance leads to competitive and sustainable battery production in Europe

- Sustainable batteries are an essential pillar of the **European Green Deal**. The ambition to be climate-neutral by 2050 requires **technological innovations** in battery value creation, through which Europe can set global trends.
- Many **European initiatives** contribute to the networking of relevant actors and to the development of an intact and sustainable battery value chain in Europe. Strategic research and development measures promote the necessary technological innovations.
- There are already numerous and diverse **cooperations and networks**. The cooperations demonstrate the activities along the entire **value chain** and contribute to accelerated development.

The European Green Deal pushes the development of advanced technologies

The European Green Deal, presented in December 2019, aims to make Europe climate-neutral by 2050 and uncouple economic growth from resource use.[57] To this end, an action plan has been established with measures covering all sectors of the economy.[58]

In addition to measures to build a circular economy (cf. chapter 2.3), investments in strategic value chains should contribute to achieving the goals. In this context, sustainable batteries are an essential pillar, as they contribute, among other things, to the decarbonisation of transport (cf. chapter 2.1.1) and to the better usability of renewable energies.

Within the framework of the European Green Deal, the goals of the Strategic Action Plan for Batteries[59] are to be further implemented and the development of new innovative value chains is to be promoted. A key objective of the Strategic Action Plan for Batteries is to build and strengthen internationally leading industrial technologies through increased research and innovation investments. Through innovative projects, a competitive and highly scaled battery cell production is to be established, which, supported by a closely networked value chain, forms a sustainable European battery ecosystem.

The requirement to be climate-neutral by 2050 and the associated necessary technological innovations are helping Europe to set new impulses and catch up with established battery cell producers.

Pan-European cooperation enables the development of innovative battery technologies

The establishment of sustainable battery production and a functioning value chain is complex and requires a high degree of cooperation and collaboration in order to make use of European locational advantages. Scandinavia, for example, offers access to raw materials through refineries and, in some cases, its own deposits. The strong automotive industry in Germany, France and Spain, among others, potentially represents a strong sales market for batteries manufactured in Europe. Short transport distances between locations minimise logistical and economic risks (see chapter 2.5). For the development of new supply chains, it

55 Transport & Environment, 2021b

56 VDA, 2020

57 European Commission, 2019a

58 EU COM, 2019b

59 European Commission, 2018

is therefore important not only to qualify existing locations, but also to establish and connect new locations.

To facilitate cooperation and strengthen collaboration, the European Battery Alliance (EBA) was launched in 2017. The EBA connects stakeholders from science, industry and politics with the aim of building and establishing a sustainable and competitive battery value chain in Europe. Under the leadership of the European Institute of Innovation and Technology InnoEnergy (EIT InnoEnegry) and involving more than 120 stakeholders along the entire value chain, 43 measures were identified that are necessary for the establishment of a European battery value chain. Of these, 18 actions were highlighted as particularly important, forming the basis for the Strategic Action Plan for Batteries (see info box on page 20).

The activities of the EBA are complemented by other initiatives. Important Projects of Common European Interest (IPCEI) specifically promote research, development and innovation along the entire battery value chain. Besides the IPCEI on Batteries under French coordination, the IPCEI "European Battery Innovation" (EuBatIn) is being implemented under German coordination. In both IPCEI

Participants and locations of the projects funded by IPCEI on Batteries and IPCEI EuBatIn

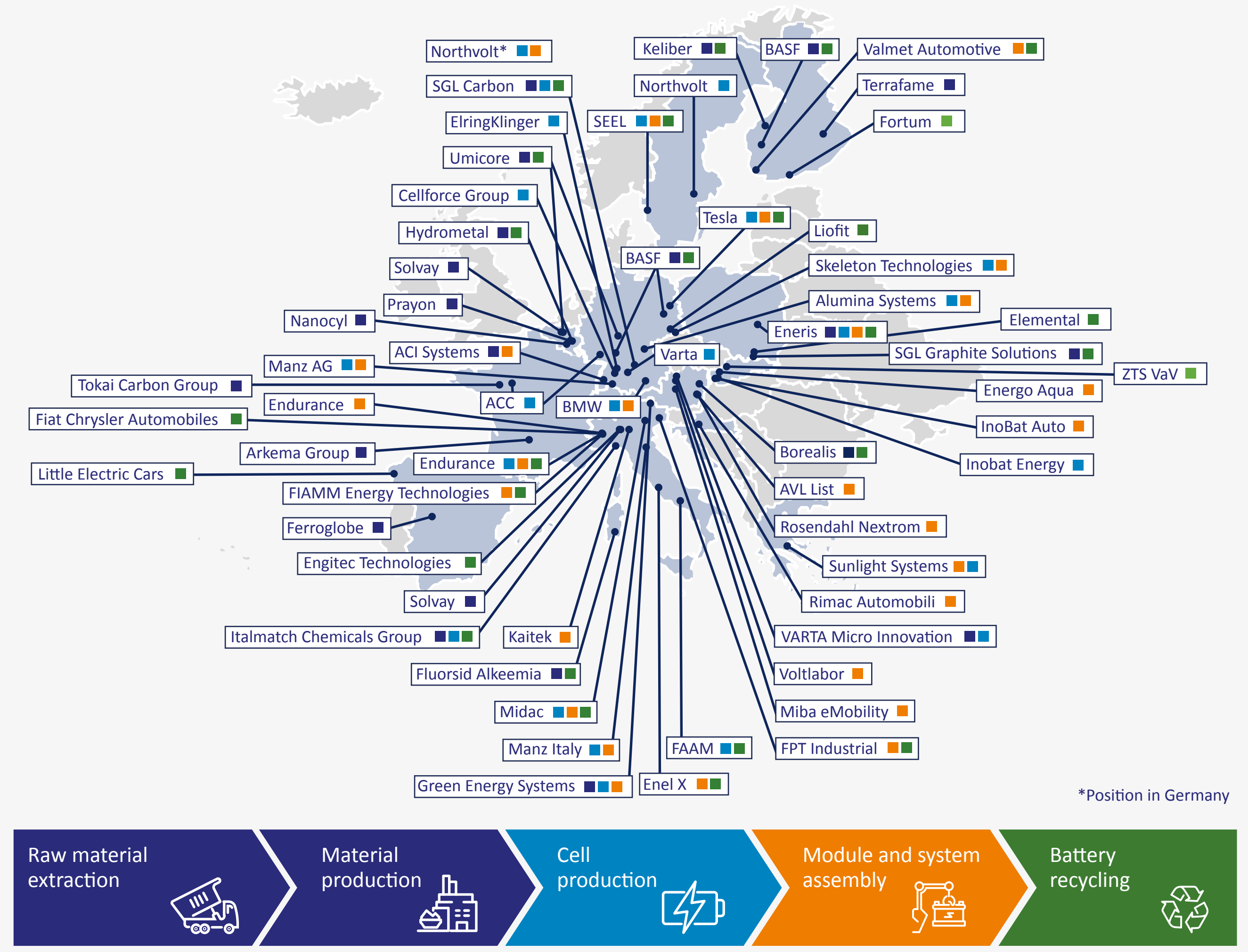


Figure 4: Participants and locations of the projects funded by IPCEI on Batteries and IPCEI EuBatIn. The colours next to the company names indicate which stages of the value chain the projects address. Own representation.

18 priority actions to establish a European battery value chain

Secure access to sustainably produced battery raw materials at reasonable costs

1. Secure access to raw materials from resource-rich countries outside the EU.
2. Facilitate the expansion/creation of European sources of raw materials.
3. Secure access to secondary raw materials through recycling in a circular economy of batteries.

Make Europe the global leader in sustainable battery technology

4. Support the growth of a cell manufacturing industry, with the smallest environmental footprint possible. This will provide a key competitive and commercial edge against competitors.
5. Create and sustain a cross-value chain ecosystem for batteries. This includes mining, processing, materials design, second life, and recycling within the EU, encouraging cross-sectoral initiatives between academia, research, industry, policy, and the financial community.

Support European battery manufacturing in order not to miss the expected massive growth in market demand (250B€ per year in 2025)

6. Ensure the availability of high-quality and high-performance cells for European industries for the purpose of maintaining the competitiveness of several European industries.
7. Front-loading financially, e.g. IPCEI (Important Projects of Common European Interest) and/or other financial instruments such as tax incentives, the necessary investments are a must in order to be prepared for demand uptake.
8. Accelerate the process and cut time to market to meet market demand and surpass international competitors.

Create and support new markets for batteries, e.g through the “Clean Energy” & the “Mobility” packages. This also includes new initiatives, to support sustainable solutions for power, transportation and industry sectors in line with EU climate goals.

9. Increase the demand for e-mobility solutions including “yellow machines”.
10. The function of batteries and battery systems must be seen as plurifunctional, in the context of both power and transportation sectors. For ESS, regulation (or absence of regulation) enabling the right business models is crucial.
11. Use incentives to make storage an alternative to conventional grid reinforcement.
12. Enable integration of ESS at all levels of the power system including behind the meter.

Grow Europe’s R&I capacity. Develop and strengthen skilled workforces in all parts of the value chain and make Europe attractive for world-class experts.

13. Create a competitive advantage with constant incremental (e.g. lithium-ion) and disruptive (e.g. solid state) R&I linked to the industrial ecosystem. This applies to all the steps of the value chain (advanced materials, new chemistries, advanced manufacturing process, BMS, recycling, business model innovations).
14. Conduct advanced research in battery chemistry, battery systems, manufacturing and recycling. Increase universities’ output in these areas through the involvement of industrial stakeholders.
15. Attract worldwide talent with lighthouse projects for cell manufacturing. This is necessary because sufficient and key human capital skills are missing in Europe, especially in the field of applied process design.
16. Make Europe attractive for world-class experts and create a competent workforce.

Involve the EU citizens in the journey: inform, educate & motivate

17. At the end of the supply chain there is always a B2C transaction. Public-sector efforts (education in schools, role modelling and so on) should be invested in the general population’s awareness and understanding of the entire value chain so that there is relevant societal appropriation from the start. Fighting to keep the supply chain in Europe will definitely help bridge the gap between the EU citizens and the politicians.

Ensure maximum safety for European citizens and create a competitive advantage through standardisation

18. Standardise storage-related installations and safety rules, including charging infrastructure, active load compensation and the enabling of vehicle-to-grid solutions.

projects, companies are developing advanced solutions to build a pan-European sustainable battery value chain with the participation of other stakeholders (cf. chapter 2.2.2). Figure 4 provides an overview of the participants funded by the two IPCEIs and the locations where the projects are being implemented.

Batteries Europe with the European Technology and Innovation Platform (ETIP) coordinates and implements research and development activities along the battery value chain. Through six thematic working groups, challenges are specifically identified and suitable solution strategies developed.

The European Raw Material Alliance (ERMA) aims to secure Europe's supply of critical and strategic raw materials. This can be achieved, for example, by diversifying sources of supply from third countries, strengthening European mining or promoting closed material cycles.

Battery 2030+ is an initiative that aims to coordinate and advance medium to long-term research and development of new battery technologies in addition to the short and medium-term measures. In particular research institutions are represented in this initiative, as it is primarily intended to answer fundamental research questions. An overview of selected European initiatives, their purpose and results to date is shown in Figure 5.

Cooperations increase efficiency, enable joint learning and ensure sustainability along the entire value chain

Direct collaborations between companies accelerate the development of the battery value chain as they can simplify knowledge building, drive networking along the supply chain and reduce costs.

In the field of recycling, for example, there is a strategic cooperation between BASF, Fortum and Nornickel.[60] Within the framework of this cooperation, Fortum will take over the recycling of the spent batteries, Nornickel the refining and BASF the production of precursor material for the cathode production. All three partners have production facilities in Harjavalta, Finland, so that transport distances can be kept short. In the field of mechanical engineering, there is a cooperation between Grob Werke and Manz.[61] Here, the two partners bring a different product portfolio to the partnership and can thus offer fully integrated solutions from cell production to battery system assembly from a single source. A third example is the cooperation between CATL and Hoppecke.[62] Thanks to this cooperation, CATL does not have to establish an independent service network in Europe, but can draw on the existing European service network of the medium-sized company Hoppecke. Hoppecke is responsible for testing, repairing and replacing lithium-ion batteries in commercial electric vehicles. There is a far-reaching cooperation between Umicore, Northvolt and BMW, from material production to cell manufacturing and product integration to recycling. The aim of this pan-European cooperation is to establish a sustainable value chain with closed cycles.[63]

Another form of cooperation is joint ventures (JV) between companies. The cooperating companies usually participate financially in the JV and can thus reduce individual costs and risks when opening up new business fields. In the field of battery cell production, for example, the Automotive

60 Werwitzke, 2020a

61 Bönninghausen, 2021

62 Werwitzke, 2020b

63 Umicore, 2018

European initiatives

	European Battery Alliance	Battery 2030+	BatterRIes Europe	IPCEI on Batteries IPCEI EuBatIn	European Raw Material Alliance
Purpose	Networking, establishment of battery value chain	Coordination of basic research	Coordination of applied research	Establishment of battery value chain	Raw material supply
Results	43 Measures for the establishment of the battery value chain	Battery 2030+ Manifesto	BatteRIes Europe Strategic Research Agenda	R&D for the establishment of a sustainable battery value chain	Cluster on Materials for Energy Storage and Conversion
	Business Investment Platform	Battery 2030+ Roadmap	Raw Materials and Recycling Roadmap		

Figure 5: European initiatives to establish a sustainable battery ecosystem and their measures. Own representation.

Cells Company (ACC) JV was concluded between PSA and Saft. While Saft contributes expertise in the field of battery technology to this JV, PSA contributes expertise from vehicle manufacturing. Joint research and development centres will enable synergies to be exploited, costs to be saved and application-oriented batteries to be developed. Based on the results of the research and development, a battery production on a GWh scale is to be established, which could supply batteries to other manufacturers in addition to the PSA fleet.[64] Another example is the Kion Battery Systems JV between Kion and BMZ Group, which jointly develops battery systems for Kion's industrial trucks.[65] The JV has set up its own production facility, which has increased production capacity and expanded the product range. A comparable JV has been formed with JT Energy Systems GmbH between Jungheinrich AG and Triathlon Holding GmbH.[66]

In the area of resource extraction, the JV between Ganfeng Lithium and International Lithium Corporation (ILC) has acquired licences to mine lithium in Ireland. Both companies have a financial interest in the JV and thus share the costs of the feasibility studies for the development of this project.[67]

New supply relationships will further consolidate the European battery ecosystem that is currently being established. In the field of battery cells, for example, BMW has signed a long-term supply contract with Northvolt. This supply contract will enable BMW to cover part of its battery requirements from 2024 on. BMW also purchases batteries from Samsung SDI, which operates a plant in Hungary, and from CATL, which will open a plant in Erfurt.[68] Northvolt, in turn, has further supply relationships with the Swedish motorbike manufacturer Cake[69] or Epiroc, a Swedish

64 Schaal, 2020a

65 KION, 2020

66 Jungheinrich, 2019

67 ILC, 2018

68 Schaal, 2020b

69 Schaal, 2020c

manufacturer of mining machinery.[70] In cathode materials, Umicore is building a plant in Nysa, Poland, from which it will supply LG Chem's (since 2020 LG Energy Solutions) Polish cell production in Wroclaw.[71] In addition to the supply of cathode material, cooperation in the area of recycling is also planned.[72] Within the area of battery components, ElringKlinger has signed a long-term supply contract for cell contact systems with a global cell manufacturer that is currently setting up a plant in Germany. [73]

To ensure sustainable value creation, companies participate in initiatives dedicated to this topic. Examples include the Initiative for Responsible Mining Assurance (IRMA) or the Responsible Minerals Initiative (RMI), which unites interest groups and companies with the aim of ensuring ecologically and socially sustainable raw material extraction. Another example is the Science Based Targets (SBT) initiative, which calls on companies to set CO_2 targets and supports them in implementing the targets. A third example is the Global Reporting Initiative (GRI), which develops guidelines and standards for corporate sustainability reports in order to standardise them and ensure easier comparability. In this way, strengths and weaknesses can be assessed more easily and potential for improvement identified.

The cooperations and initiatives mentioned here provide an exemplary overview of activities in Europe and make it clear that not only cell production is being established, but that the entire value chain is being taken into account. They represent only a small section of the currently very strongly growing European battery ecosystem, which was examined in more detail in a separate study.[74]

2.2.2 Decided public support for battery cell production is crucial for the sustainable development of a European battery ecosystem

- From an **innovation policy perspective**, the state has a dicisive role.
- State support may be necessary due to **"capital market failure".**
- **Catching up with Asian competitors** can be facilitated **by targeted promotion** of innovations in the European battery value chain.
- The promotion of electric mobility / battery cell production does **not** represent a **break with the principle of technology openness.**

From the challenge of effective climate protection derives the task for the state to facilitate **industrial structural change**. Whether this should be done via price signals and innovation promotion, i.e. the instruments of a **horizontal industrial policy**, or via technological regulation up to state-organised investments in production facilities, i.e. a more **interventionist industrial policy**, is part of an extensive debate on climate and industrial policy.[75]

Essentially, the state has a decisive role from an innovation policy perspective. It bears a great responsibility for enabling the necessary structural change and actively stimulating it, especially where market forces are not sufficient.[76]

There are three arguments in particular that can be used to justify industrial and innovation policy action by the state:

- Uncertainty, which differs from risk in that no probability distribution is known for the possible outcomes,
- Network effects and externalities that require coordinated action by private and public actors,

70 Schaal, 2020d

71 Schaal, 2020e

72 Bönninghausen, 2019

73 Werwitzke, 2021

74 Gieschen et al., 2021

75 Bardt, 2019

76 Schmidt, 2019

- Path dependencies resulting from high fixed costs and the long lifespan of investments, especially in the energy sector.

State support in the event of market failure
According to Bofinger, from a strategic point of view, industrial and innovation policy action may also be warranted if other economically significant countries pursue an active industrial policy that can lead to disadvantages for domestic suppliers in global competition.[77]

"The problem of uncertainty or at least very high risks can cause private actors to refrain from innovative investments, although they do not fundamentally assess them negatively in terms of their earnings potential. This situation is often referred to as capital market failure" (Bofinger 2019).[78]

Due to the high market preeminence of Asian cell manufacturers and the considerable investments required, there are high market entry barriers for new (European) competitors.

Catching up with Asian competitors is facilitated through targeted promotion
Basically, according to Bofinger, the challenge of catching up with Asian and especially Chinese manufacturers can only be successfully taken up by joint European efforts. "Only if Europe stands united is there a chance of unleashing the economies of scale currently available to investors and innovators in the Asian/Chinese market" (Bofinger 2019).

One approach to a solution in this context is the effort of the European Commission and the German Federal Government to promote their own production of battery cells via a European Battery Alliance.[79] To this end, at the beginning of 2019, numerous EU member states, under the leadership of France and Germany, together with the European Commission, decided on two major projects, so-called Important Projects of Common European Interest (IPCEI), for research and development in battery cell production. The two IPCEIs were approved by the EU Commission at the end of 2019 and the beginning of 2021, respectively, following an examination of their conformity with state aid law, and include national funding of over 6 billion EUR for the EU member states alone (up to 3 billion EUR will be provided by the German Federal Government). Added to this are funds from the regions in which the funded projects will be located, as well as investments from industry. In Germany alone, this will trigger investments of over 13 billion EUR, as a result of which several thousand skilled jobs will be created in the next few years and several tens of thousands by the end of this decade.[80] [81] [82]

Battery IPCEIs - critics and proponents of interventionist industrial policy
For the interventionist industrial policy in the form of the two battery IPCEIs, both critics and advocates can be found.

The German government's Council of Economic Experts comes to a **rather critical assessment of battery subsidies**. According to it, subsidising the production of battery cells itself does not appear to be expedient. "Production is capital and energy intensive. A large part of the value creation lies in the resources and the production is automated to a large extent. The employment effects are therefore likely to be small.[83] Although the leading producers of battery cells are concentrated in Asia, competition between suppliers seems to work though.[84] This suggests that the purchase prices for batteries are likely to be competitive prices and therefore do not threaten the competitiveness of European or national car manufacturers".[85]

77 Bofinger, 2019

78 Siehe dazu auch: Chang et al., 2013

79 Bofinger, 2019

80 BMWi, 2021d

81 Frese, 2021

82 BMWi, 2021a

83 Falck & Koenen, 2019

84 Falck & Koenen, 2019

85 Sachverständigenrat, 2020

The principal criticism is that production subsidies are flawed with many problems. For example, subsidy commitments despite a lack of information on the part of the state or due to certain political preferences harbour the danger of political influence[86], and a subsidy for battery cell production sets various false incentives.[87]

However, this critical voice can be contrasted with numerous **arguments** put forward **by the proponents of the two battery IPCEIs**. In addition to the mobilisation of considerable private investment and the associated creation of a large number of skilled jobs, the EU Commission justifies the approval of the IPCEIs under state aid law primarily on the grounds that they contribute to a common goal. In particular, as it concerns a value chain that is of strategic importance for the future of Europe, especially with regard to clean and low-emission mobility. At the same time, the IPCEIs are considered very ambitious, as they aim to develop technologies and processes that go well beyond the current state of the art and will enable major improvements in terms of performance, safety and environmental protection. As the projects funded within the IPCEIs also involve significant technological and financial risks, public support is considered necessary – also to create investment incentives for companies. Aid to individual companies is limited to what is necessary and must not unduly distort competition. In this respect, the Commission has in particular verified that the maximum aid amounts envisaged correspond to the financing gaps in relation to the eligible costs of the projects. Companies will also repay part of the taxpayers' money received to the member states concerned if their IPCEI project is very successful and generates net revenue. Moreover, only projects involving several member states, involving private investment by the beneficiaries and generating positive spill-over effects across the EU will be supported. Consequently, even countries or companies located there, but not being part of the IPCEIs also benefit, as the results of the projects are passed on to the European scientific community and many other companies from other countries as well (spill-over).

In addition, the funded projects of the two battery IPCEIs cover the entire battery value chain – from the extraction of raw materials, the design and production of battery cells and battery systems to recycling and disposal in a circular economy, always with a focus on sustainability. The funded projects are expected to contribute to a whole range of new technological breakthroughs, encompassing various cell chemistries and novel production processes, as well as further innovations in the battery value chain.

In both IPCEIs together, the number of direct participants adds up to 59 and the cooperations with external partners to more than 220. This makes it possible to realise or intensify a broad networking of the actors across value creation stages and thus a knowledge transfer, especially between battery cell and material manufacturers, as well as a technology transfer between the participating industrial sectors and research. In this way, the participants can contribute to turning the already existing strengths into successful products.[88] [89]

The **industry** also **sees** the **IPCEI as** a **positive instrument** for testing, launching and scaling innovative technologies in sectors and markets affected by market failure, as it strengthens technological sovereignty and, with regard to battery cell production, ensures the availability of battery components and creates sustainable jobs. For example, BASF, a company funded within the first battery IPCEI, emphasised that its own investment associated with the funding was a clear endorsement of a European battery production value chain.[90] BMW is also involved in the battery IPCEIs with research and development projects and is developing innovative, sustainable, function-optimised and cost-efficient battery cells, which BMW says should be considered a key element of a European cell and battery value chain. According to the company, the research results achieved within the IPCEI projects strengthen the establishment of an integrated European battery value chain and pave the way for successful battery cell development and production in Europe.[91] From the point of view of the BMW Group

86 Sachverständigenrat, 2019

87 Sachverständigenrat, 2020

88 European Commission, 2021b

89 European Commission, 2019c

90 BASF, 2020

91 BMW, 2021

(Peter Lamp, Head of Battery Cell and Fuel Cell Research and Development), the most important goals of the battery IPCEIs are to reduce geopolitical dependency in the battery cell market and to build up a European partner network for battery cells. [92]

Promotion of battery cell production is not a break with technological openness

With regard to the promotion of electromobility and battery cell production, some voices can be heard that see this as a departure from the **principle of technology openness**.

Thus, no matter how well-informed a government is, it cannot know what market outcome is possible in an innovative process and which company can best achieve it. "Picking the winners", i.e. selecting and promoting a certain company or a certain technology, eliminates competition, hinders the necessary innovations and in this respect is not a convincing answer to the dynamics of the upcoming fundamental change processes.[93] Also it is not clear whether the battery-electric vehicle will be able to establish itself as the leading technology in the future. In the long term, fuel cells can be expected to replace batteries in several vehicle segments.[94] The VDA has also always spoken out in favour of an open technology and rejected a commitment to only one low-emission type of drive, insisting that battery-electric vehicles as well as fuel cell technology and synthetic fuels represent possible decarbonisation options.[95]

Critics emphasise that the concept of technology openness ultimately leads to a consolidation of the status quo and that no change processes can be forced without specifications. Accordingly, VW boss Diess criticised the VDA and demanded that the association clearly position itself on battery-electric cars as the technology of the future.[96] This would be tantamount to a caesura and could herald a dynamic renewal of car manufacturers, at least with regard to drive technology. Nevertheless, the Platform for the Future of Mobility has named synthetic fuels as a possible building block for the decarbonisation of car traffic. In this respect, it is not conceivable whether the automotive industry will unanimously abandon the concept of technology openness.[97]

With regard to the necessary ecological / sustainable transformation of the transport sector, the fact that policy and political decision makers are not turning away from the principle of technology openness is shown in particular by the fact that, with the aim of largely neutralising greenhouse gases in the transport sector, in addition to the promotion of battery cell production, other alternative drive types and concepts are being given broad and increasing consideration in German and European funding strategies and programmes.

This is especially true for hydrogen as an energy carrier. Particularly in terms of financial volume, the promotion of hydrogen reaches a similar, if not higher, level than battery cell production. For example, a funding volume of up to 1.4 billion EUR is available within the framework of the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP) in the period from 2016 to 2026. Also, application-oriented basic research on green hydrogen will be further expanded within the framework of the Energy and Climate Fund with 310 million EUR from 2020 to 2023, and it is intended to strengthen application-oriented energy research on hydrogen technologies with 200 million EUR from 2020 to 2023. In addition, there are the " Real Labs of the Energy Transition", which accelerate the transfer of technology and innovation from research to application, also in the case of hydrogen, and for which funding of 600 million EUR has been earmarked for the period from 2020 to 2023. Within the framework of the National Decarbonisation Programme, investments in technologies and large-scale plants in industry that use hydrogen to decarbonise manufacturing processes are being promoted, among other things. More than 1 billion EUR will be available for this purpose from 2020 to 2023. In addition, the German government's Corona-related economic stimulus package of June 2020 provides for a further 7 billion EUR to be made available for the market

92 Günnel, 2020

93 Bardt, 2019

94 NM, 2021

95 Haas, 2020

96 Mortsieffer, 2019

97 Haas & Jürgens, 2019

ramp-up of hydrogen technologies in Germany and a further two billion EUR for international hydrogen partnerships.[98]

Furthermore, the European level is also increasingly focusing on hydrogen as an energy carrier. The European Hydrogen Strategy for a climate-neutral Europe, presented on 8 July 2020, is intended to lay the foundation for the development of a green hydrogen infrastructure in Europe. Green hydrogen is to become competitive by 2030 with the help of EU funds and advance the energy transition.[99] This is to be supported by an IPCEI, which – led by the German Federal Government – is to enable projects along the entire value chain from the production of green hydrogen via infrastructure to the use of hydrogen in industry and mobility. A total of several billion EUR from the federal government's economic stimulus package and state funds are to be made available for this purpose.[100] Moreover, 22 EU member states and Norway have already signed a declaration of intent in which they declare their willingness to support the development of a European value chain for green hydrogen in particular and to make corresponding investments worth billions of EUR. The participating countries describe the commitment to hydrogen as a technology of the future as crucial to making Europe a climate-neutral continent by 2050.[101] Meanwhile, the BMWi and the Federal Ministry of Transport and Digital Infrastructure (BMVI), together with the federal states, have pre-selected 62 projects in Germany alone, by means of an application procedure, which are to be funded with up to 8 billion EUR within the framework of such a hydrogen IPCEI.[102]

2.3 Circular economy

- The current proposal for a **Regulation on batteries and waste** presents a wide-ranging package of measures to **establish a circular economy**.
- The increasing number of used batteries and the associated opportunity for **automation** and **increased efficiency** are key levers for **increasing the economic efficiency** of recycling processes. The battery packs currently used in vehicles will probably reach the end of their life in about eight to 15 years. This window of opportunity must be used to further upgrade existing plants and to build up new recycling capacities.
- The processing and **reuse of spent batteries** improves the ecological footprint of batteries. Due to the currently very high market dynamics and falling battery prices, the economic establishment of second-life business fields is challenging. Suitable framework conditions such as design guidelines or guidelines on battery data availability can contribute to cost reduction.

2.3.1 Political requirements and the expansion of production capacities enable the recycling of batteries

Political requirements create the framework conditions for establishing a battery circular economy

Political requirements, e.g. in the form of ordinances or laws, are an effective means of establishing and shaping a battery recycling economy. The *Act on the Marketing, Return and Environmentally Sound Disposal of Batteries and Accumulators (Battery Act)* transposes the *European Directive on Batteries and Accumulators and Waste Batteries and Accumulators (2006/66/EC)* into German law and specifies, for example, collection quotas for waste batteries or regulates the implementation of take-back systems for waste batteries.

98 BMWi, 2020b

99 Future:fuels, 2020; European Commission, 2020f

100 BMWi, 2021e

101 Werwitzke, 2020c

102 Schaal, 2021b

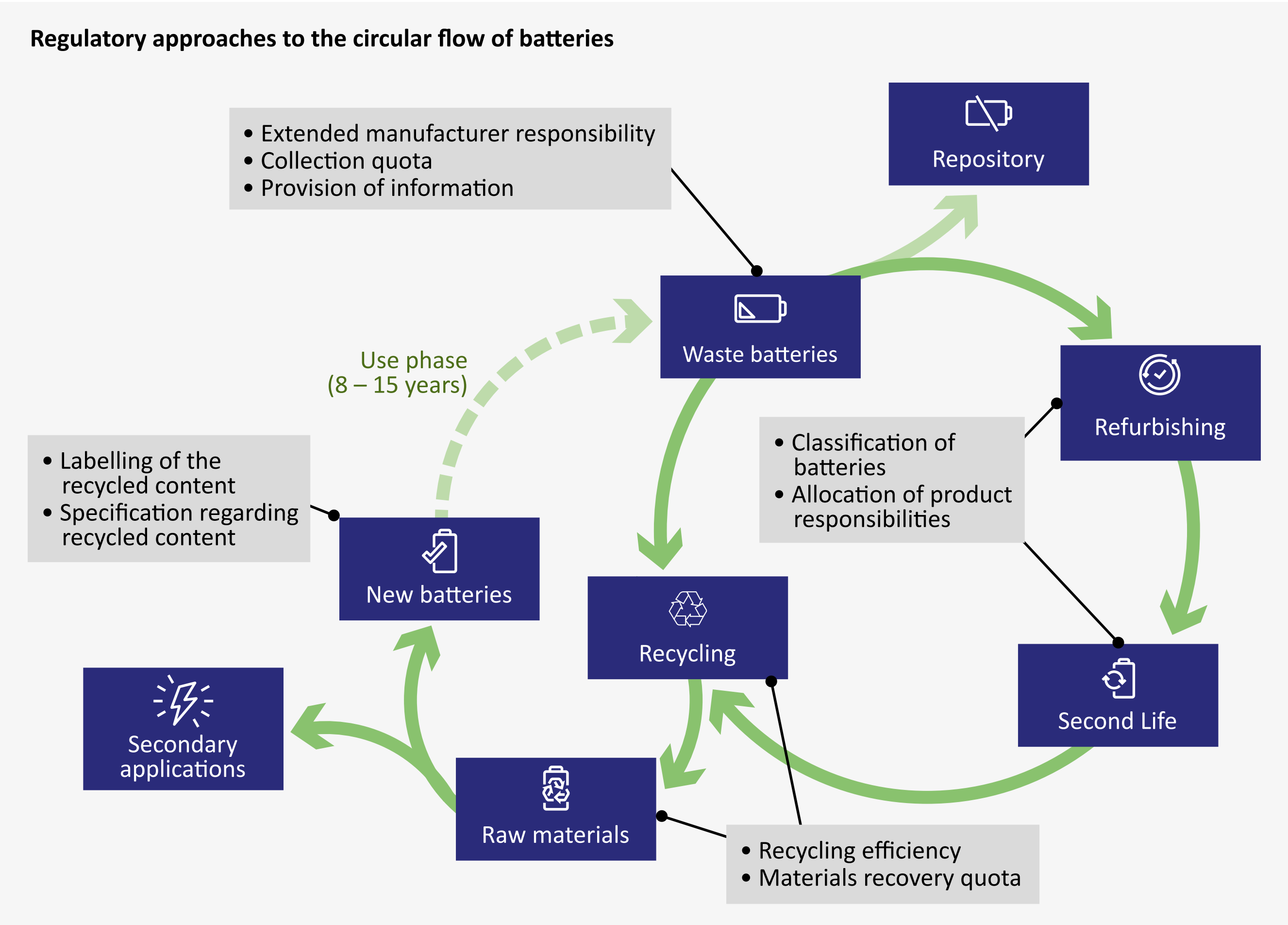


Figure 6: Possible paths for the recycling of spent batteries. The boxes highlighted in dark grey show the regulatory approaches to strengthening a battery circular economy. Own representation.

In order to expand the legal framework, the European Battery Directive 2006/66/EC is currently being revised. In the form of a new European Battery Ordinance, the revision is intended to create a legal framework that not only regulates the handling of spent batteries more comprehensively, but also includes the production and use phase of batteries.[103] This legal framework is intended to provide planning security and enable the **development and establishment of new business areas in the field of battery recycling management.**

The current proposal for a Regulation on batteries and waste was published on 10 December 2020 and identifies measures in several articles that are conducive to establishing a battery circular economy. Some of the most beneficial measures are shown in Figure 6 in the form of boxes with a dark grey background. On the one hand, the illustration visualises the possible paths for recycling spent batteries, and on the other hand it clarifies at which point in the cycle the measures would take effect.

Extended producer responsibility obliges battery producers to organise and finance the collection and treatment of spent batteries. Depositing of spent batteries is thereby prohibited. It thus lays an important logistical foundation for ensuring the recyclability of batteries.

103 European Commission, 2020e

The **collection rate** is intended to ensure that as many spent batteries as possible remain in the recycling system. The Battery Act, which has been in force since January 2021, stipulates a collection rate of 50% for portable batteries. The current proposal for a Regulation on batteries and waste batteries provides for the collection rate for portable batteries to be increased to 65% from 2025 and to 70% from 2030. For spent batteries from electric vehicles, a 100% collection rate is determined.

The **provision of information** ensures that necessary information for the **classification of spent batteries** is available. The current proposal specifies that this information should include the chemical composition and information on the remaining capacity, among other things. This should simplify decisions as to whether the waste battery is suitable for reprocessing or recycling. In addition to the labelling of batteries, the information is to be made available electronically via a battery passport accessible by QR code (see info box “What is a battery passport?”)

The **regulation on product responsibility for second-life batteries** requires remanufacturers to ensure that recycled batteries meet the requirements of the revised European Batteries Regulation in terms of product, environmental and health requirements. Exceptions are only possible if the reprocessed batteries came onto the market before the new European Batteries Regulation came into force.

The **recycling efficiencies** and **material recovery rates** specify what percentage of spent batteries must be recycled and what percentage of raw materials must be recovered. For lithium-ion batteries, the proposal for a Regulation on batteries and waste batteries specifies a recycling efficiency of 65% for 2025 and of 70% for 2030. From 2025, the material recovery rates are to be 90% for cobalt, nickel as well as copper and 35% for lithium. From 2030, the recovery rates are to be increased to 95% for cobalt, nickel and copper and to 70% for lithium.

From 2027, **labelling of the recycled content** in new batteries is to be made mandatory by the new Batteries Regulation. From 2030, **minimum recycling percentages** are to be compulsory for the use of cobalt, nickel and lithium in the active materials. The recycled share is to be at least 12% for cobalt, at least 4% for nickel and also at least 4% for lithium. From 2035, this share is to be increased to at least 20% for cobalt, 12% for nickel and 10% for lithium. By specifying minimum recycling percentages, it can be ensured that part of the battery materials are recycled with a sufficient quality for reuse and do not pass into secondary applications in a poor quality.

The measures listed here show a variety of factors for establishing a battery recycling economy and thus form a basis that can provide planning security and contribute to the development of new business areas such as the processing and sale of second-life batteries. It should be noted, however, that the current version of the new regulation is a draft that is still under discussion and may be amended. Industry associations such as Eurobat[104] and ZVEI (the German Electrical and Electronic Manufacturers' Association),[105] for example, criticise the specification of minimum recycling percentages as difficult to verify and implement. In particular, a low availability of recycled material could be problematic, as current batteries are expected to last eight to 15 years.[106] Currently, a strong increase in battery demand is predicted, [107]so that the recycled material available in eight to 15 years could only cover a small fraction of the demand. Due to the low availability, the price of recycled material could rise sharply and lead to a competitive disadvantage for European producers.

It is not yet possible to say with certainty which measures will be included in the new European Batteres Regulation and in what time frame they will be implemented. However, thanks to the fundamental willingness of the European battery industry to participate in a circular economy,[108] it can be assumed that the new EU Batteries Regulation will be a stable basis for the development and establishment of new business fields.

104 EUROBAT, 2021

105 ZVEI, 2021

106 IEA, 2020

107 Slowik et al., 2020

108 EUROBAT, 2020

The ramp-up of electric vehicle production will improve the economics of battery recycling

Due to limited natural raw material deposits for the production of lithium-ion batteries within the European Union, the raw material demand cannot be covered exclusively from European sources. The recycling of lithium-ion batteries reduces the need for raw material imports, thus leading to more raw material independence. For economically viable raw material independence, it is necessary that the recovered secondary raw materials are offered at competitive prices compared to primary raw materials.[109]

Rising registration numbers of electrically powered vehicles will lead to increased demand for battery raw materials, which in turn can be expected to increase prices for primary raw materials and reduce price pressure for secondary raw materials. However, the recent past shows that prices for primary raw materials can fluctuate strongly due to scalable mining capacities. Consequently, predicted raw material prices are subject to high uncertainties, so that it is unclear how much the pressure on prices for secondary raw materials will change.[110]

A significant contribution to reducing recycling costs can be made by the growing proportion of old batteries, corresponding to the rising number of registrations. Due to the low registration figures to date, the return of battery packs from old electric vehicles is low. In 2019, a total of 5,708 t of used lithium-ion batteries were generated in Germany, which originate from battery packs from old electric cars or from recall campaigns, among other things.[111] This compares to a recycling capacity of over 16,000 t.[112] The currently still low capacity utilisation and the high complexity and variance of the battery packs mean that manual disassembly is required for further recycling steps. Due to the high weight of the battery packs, special tools are required for handling. The personnel must be technically trained to handle high-voltage batteries and, due to highly flammable and toxic substances, appropriate safety precautions must be taken.[113]

Manual dismantling and the associated effort are cost drivers that stand in the way of economic recycling. For this reason, recycling companies focus especially on the recovery of raw materials with high market prices, such as cobalt, nickel and copper.[114]

Due to the increasing amount of used batteries, recycling steps such as the disassembly of battery packs can be automated, as the plants are utilised accordingly and thus justify the high investment costs. Furthermore, higher capacity utilisation reduces transport costs. The efficiency gains achieved lead to increased profitability and an improved carbon footprint. Ultimately, the increased profitability can also make the recycling of other raw materials, such as lithium, graphite or manganese, attractive.

However, automating the recycling steps is not trivial. Disassembling a battery pack in particular is a complex task because they are not uniform. The battery packs and their components are often connected by means of welded and glued joints, which means that they cannot be easily separated.[115] Current projects such as DeMoBat[116] or ZDR-EMIL[117] are addressing this issue and developing technological solutions to automate disassembly. Design standards and uniform labelling, among other things, can contribute to reducing complexity.

109 IEA, 2020

110 DERA, 2021

111 Scholz, 2021

112 Summerville et al., 2021

113 Harper et al., 2019

114 DERA, 2021

115 Harper et al., 2019

116 Fraunhofer IPA, 2021

117 Fraunhofer IWKS, 2020

Through processing and reuse of spent batteries, raw materials are used more efficiently

As an alternative to recycling, at the end of the first use phase, the old battery can be processed and reused. As shown in the previous section, traction batteries in electric vehicles are expected to reach their end of life after about eight to 15 years. The end of life for traction batteries is usually defined as having left only 80% of the initial capacity. However, it does not mean that the battery is no longer functional. This opens up opportunities to use the remaining capacity in other applications that have lower energy density requirements. Possible applications would be, for example, stationary battery energy storage systems (BESS), which can store renewable energies temporarily and make them available as needed.

By reusing or recycling, the battery and its materials would be used for longer without the need for energy-intensive synthesis, processing or production steps. The ratio of “energy stored in the battery” to “energy used for production” would further improve, as would the battery’s carbon footprint. From an environmental sustainability perspective, the advantages of reuse are clearly evident.

However, the question arises whether reuse is also sustainable from an economic point of view. Second-life batteries have to compete with new batteries in terms of price. According to the Boston Consulting Group, users would be willing to pay a maximum of 60% of the price of a new battery for a second-life battery.[118] In view of the currently falling battery prices, there is therefore a significant loss in value during the use phase. Tesla and Volkswagen, for example, have announced that battery costs can be reduced by more than 50% through further technological development and efficiency improvements (cf. chapter 2.5). Although this cost forecast initially applies to traction batteries primarily, it can be assumed that the cost reduction will also have an impact on battery prices for stationary energy storage systems. Second-life batteries will therefore only be available at a fraction of today’s costs. The expected but difficult-to-predict price drop makes it difficult to plan business models.

In order for the processing of traction batteries for second-life storage to be economically profitable, this must be done with as few and as efficient steps as possible. However, due to the high variance and complexity described in the argument „ The ramp-up of electric vehicle production will improve the economics of battery recycling “, the dismantling of battery packs is a costly process, so that additional costs are incurred in the reprocessing of individual components, which have a negative impact on profitability. Even when battery packs are used directly, additional costs are incurred, e.g. for removal from the vehicle, condition inspection, logistics and reinstallation.

To achieve economic sustainability, it is therefore necessary to keep the effort for recycling as low as possible. As in the case of recycling, automation processes can help to reduce costs as the volume of used batteries increases. Other important fine-tuning parameters are specifications and standards that contribute to the standardisation of battery packs. For example, design guidelines could help reduce complexity. Furthermore, access to the data of the battery management system can significantly reduce the effort for condition checks or even make them obsolete.

Regardless of ecological and economic sustainability, regulatory questions, e.g. regarding extended producer responsibility or product warranty, need to be clarified. As shown at the beginning of the chapter, the currently proposed Regulation on batteries and waste batteries provides suggestions for solutions to such regulatory issues and can thus contribute to the establishment of this new business field.

118 Niese et al., 2020

Excursus: Estimation of "energy stored in battery" ratio ($Batt_{Energy}$)" / "Engergy used for production ($Prod_{Energy}$)" and influence of second-life applications

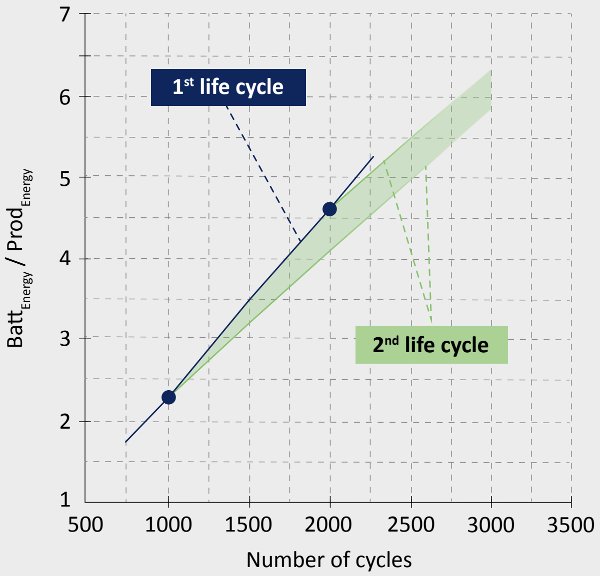
A battery pack with 23.5 kWh energy content (100 % State-of-Health [SoH]) is considered. The production of the battery pack requires approx. 1125 MJ/kWh. The entire battery pack therefore requires approx. 26000 MJ or 7.3 GWh of energy ($Prod_{Energy}$)[i].

The ratio $Batt_{Energy}$ to $Prod_{Energy}$ as a function of the number of cycles is shown in Figure 7 for the 1st life cycle and two 2nd life cycles. As a hypothesis, it is assumed that the 2nd life cycle begins once after 1,000 cycles and once after 2,000 cycles in the 1st life cycle.

Under the assumptions mentioned in the calculation, a good twice as much energy is stored in the battery at 1,000 full cycles as was used for production. If 80% SoH is only reached after 2,000 cycles, a good 4.5 times as much energy could be stored in the battery as was used for production.

Due to the lower residual capacity, the $Batt_{Energy}$/$Prod_{Energy}$ curve is flatter depending on the number of cycles for second-life applications. It is therefore desirable to run as many cycles as possible in the 1st life. Nevertheless, the improvement of the ratio with increasing number of cycles is also obvious in the 2nd life cycle.

It should be noted that this is an initial estimate based on simplified assumptions, which is intended to give an impression of how the ratio of the energy stored in the battery to the energy used for production develops as a function of the number of cycles. In particular, the prediction of cycle stability in the 2nd life cycle is the subject of many scientific studies, so that the cycle numbers shown here are of a purely hypothetical nature.



Calculation:

It is assumed that the battery pack has reached the end of the 1st life cycle at 80% SoH (18.8 kWh residual energy). The end of the 2nd life cycle is reached at 60% SoH (14.1 kWh residual energy). For the estimation, it is assumed that the battery is discharged by 80% in each cycle (Depth-of-Discharge [DoD]) and then fully charged again.

In a highly simplified way, the average value of 100% SoH and 80% SoH is calculated for the amount of energy that can be stored per cycle in the first life cycle. In the second life cycle, the mean value is taken from 80% SoH and 60% SoH.

The energy stored in the battery is estimated as follows:

$Batt_{Energy}$ (1st life cycle) = Number of cycles * DoD * (SoH_{100} + SoH_{80} / 2)

Figure 7: Estimation of $Batt_{Energy}$/$Prod_{Energy}$ as a function of the number of cycles for the first life cycle and two second life cycles. Own representation.

i Dai et al., 2019

2.4 Raw materials governance

2.4.1 Technological innovations pave the way for clean batteries

- The production of current lithium-ion batteries requires the **use of raw materials**, some of which are classified as critical.
- The further development of **technologies** in the field of raw material extraction, conditioning and processing reduce the environmental impact of raw material extraction.
- **New digital concepts** allow the complete and verifiable documentation of material and information flows of individual products in the supply chain.

Innovations can reduce or substitute critical raw materials in battery cells

The production of current lithium-ion batteries requires raw materials that, for various reasons belong to the critical raw materials (see info box). Depending on the cell technology, these are currently mainly cobalt, lithium and natural graphite. Since the commercialisation of the first lithium-ion battery 30 years ago, the functional components have been constantly modified and varied. This has often been due to technological or economic aspects. Currently, innovations are driven primarily by requirements arising from the sustainability of battery cells, as well as by the further technical optimisation of the performance parameters.

Cobalt is one of the most expensive metals in a lithium-ion battery. At currently approx. 30 thousand USD per tonne, cobalt is about twice as expensive as nickel (12 kUSD/t) or lithium (18 kUSD/t).[119] Accordingly, cell manufacturers are working intensively on reducing the cobalt content in Li-ion batteries . Today's battery generations already contain significantly less cobalt. While the cathodes of the first generations (early 1990s) still consisted of 60 percent by weight (wt%) cobalt (LiCoO2), in current variants cobalt is substituted proportionally by elements such as nickel, manganese or aluminium. Current NMC622[120] cathodes contain only 10 wt% cobalt. Tesla currently states the cobalt content of its batteries at 2.8 wt% (cobalt content based on the entire battery).[121] At the same time, the relative gravimetric energy density of NMC-based batteries has almost doubled within the last ten years, as a result of which the cobalt content is also used more effectively.[122] Cobalt-free battery cells based on lithium, iron and phosphorus (lithium iron phosphate, LiFePO4), for example, are also being used. This circumvents reputational risks, reduces costs and increases resilience in the supply chain. Numerous OEMs have already announced that they will rely on the

What are critical raw materials?

According to the EU definition, metals and minerals are classified as critical if they are important for the economy and are associated with a high supply risk. The supply risk results from the global concentration of primary raw materials, the governance of the supplier countries, environmental aspects, the contribution of recycling, substitution possibilities and the EU's dependence on imports and trade restrictions in third countries. The EU has currently identified 30 critical raw materials, including lithium, cobalt and natural graphite, which are important for batteries.[i]

From the company's point of view, factors such as price stability, reliability of suppliers and availability of certified raw materials also play an important role. In particular, raw materials that are also associated with negative aspects in the public perception (e.g. child labour in cobalt mining) can lead to a considerable reputational risk if they come from non-certified sources.

i European Commission, 2020

119 Götz, 2019

120 Note: Lithium-nickel-manganese-cobalt oxides with the chemical formula: LiNi0.6Mn0.2Co0.2O2 (=NMC622)

121 Seiwert, 2019

122 Field, 2020

more cost-effective LiFePO4 batteries[123] for their entry-level models.[124 125]

When it comes to graphite, the main component of the anodes, battery manufacturers have a choice between natural and synthetic graphite. The latter is obtained at high temperatures from coke and residues from the petroleum industry. Renewable raw materials are being investigated as an alternative carbon source. Greenhouse gas emissions in the production of synthetic graphite depend strongly on the energy mix used.[126] By adding silicon to the anode, performance increases can be achieved, which reduces the demand for graphite per kWh of battery energy.

Also battery technologies without lithium are being invented or further developed, e.g. redox flow batteries. Due to the significantly reduced energy density and the poorer efficiency, these will not be usable for mobile applications, but certainly for stationary devices. First large redox flow battery storage systems are being built worldwide. A 20 MWh pilot plant is currently being built on the premises of the Fraunhofer ICT in Pfinztal,[127] a 60 MWh plant on Hokkaido in Japan,[128] and a 10 MWh plant in Shenyang, China.[129] An 800 MWh plant in the Dalian region, China, is being planned.[130]

New technologies reduce the environmental impact of raw material extraction and enable the development of new raw material deposits

The pressure on the individual actors in the battery raw materials supply chain is rising. Many OEMs are increasingly demanding high environmental and social standards in their supply contracts. New technologies are currently being developed in the area of raw material extraction, preparation and processing in order to meet these challenges resulting from sustainability requirements.

Example lithium: For the production of lithium from brine, a lot of salt water is currently being extracted from the underground, which evaporates in large basins. Residents living in the vicinity of such extraction plants fear that the freshwater level could drop as a result. Now a German company has succeeded in extracting lithium hydroxide in a highly pure form directly from residual brine. Until now, the residual brine has been a waste product of lithium production that had to be disposed of. A great advantage is that no additional brine has to be extracted and the groundwater level is not lowered any further. A planned project for the industrialisation of this technology is already in preparation.[131]

Example nickel: In Finland, a company is starting a project to extract nickel using bio-leaching. In this process, microorganisms are used to dissolve metals from the ore in an energy-efficient way and to collect them. The desired nickel salts can then be precipitated directly from the leaching solution. In this way, waste dumps with low ore content can be made usable and at the same time battery raw materials with a significantly lower CO_2 footprint (up to -60%) can be offered.[132]

Recycling: Recycling also plays an important role. Several large OEMs have announced their intention to build their own recycling plants for their batteries: On the one hand, to tap into new sources of raw materials, and on the other

123 Note: Phosphorus is listed as a critical raw material by the EU. This is due to the limited availability of primary phosphorus sources as well as the high economic importance for agriculture. Compared to agriculture, global iron phosphate battery production will only account for a small share of phosphate demand.

124 Seyerlein & Prawitz, 2020

125 Zhang, 2020

126 Dolega et al., 2020

127 Fraunhofer ICT, 2021

128 Solarserver, 2013

129 Rongke, 2012

130 Vanadium, 2020

131 ACISA, 2021

132 Terrafame, 2020

hand, to meet the requirements of future regulation (see chapter 1.3).[133] [134] [135] Up to 95% of battery materials can already be recovered using modern hydrometallurgical recycling processes.[136] These technologies thus allow a genuine recycling of valuable battery raw materials and have the potential to reduce Europe’s dependence on raw materials in the future.

New digital technologies in product tracking and the sustainable handling of raw materials create transparent and responsible supply chains.

New digital technologies and concepts (“digital twin”) in the supply chain allow the complete and verifiable documentation of material and information flows for a single product. For example, Volvo/Polestar has announced that, together with its battery cell supplier and blockchain specialist Circulor, it will use new raw material traceability technologies to securely track cobalt in its supply chain.[137]

A similar project is also being driven forward by Ford together with blockchain specialist Everledger.[138]

The Re|Source Initiative, founded by CMOC, Glencore and ERG in 2019, recently announced plans to roll out a blockchain-based system as early as 2022 that will enable “tracking of responsibly produced cobalt from the mine to the electric car”.[139]

At the World Economic Forum 2017 in Davos, more than 40 different representatives from industry, NGOs and government organisations joined forces to form the Global Battery Alliance. It is on its way to becoming an independent non-profit organisation. One of its flagship projects is the development of a battery passport, a digital twin of each battery. The battery passport is intended to enable a secure and non-discriminatory exchange of data between stakeholders in the battery value chain and at the same time create the necessary transparency for public and private institutions. The aim is to increase transparency in the supply chain, ensure the secure traceability of raw materials and collect data uniformly at economic, social and environmental levels.[140]

The battery passport aims to bring together essential information on battery sustainability and performance to provide reliable information to battery users. Workshops, resellers, second-life users and recyclers should also be able to benefit from the battery passport, enabling them to make informed business decisions. In this way, data on the battery history, the state of health and the battery chemistry or composition can be used to reliably determine the remaining service life or the residual value of a battery or to estimate the economic efficiency for second-life applications. The battery passport therefore has the potential to increase confidence in battery raw materials, meet legislative requirements (e.g. the introduction of a battery passport as envisaged in the proposal for a Regulation on batteries and waste batteries) and at the same time catalyse circular business models.

What is a digital battery passport?

The battery passport concept provides for the creation of a digital twin for each battery. This twin combines (verifiable and forgery-proof) information on material provenance, battery performance, CO_2 footprint and, if applicable, other environmental indicators. Users of batteries will have access to this information, which will help them make informed business decisions. In the new proposal for the EU Batteries Regulation, a battery passport is required for batteries with an energy of more than 2 kWh.

133 Ingenieur.de, 2019

134 BMW, 2020a

135 Volkswagen, 2019a

136 Kunde, 2019

137 Polestar, 2021

138 Roman, 2021

139 Randall, 2021

140 World Economic Forum, 2020

2.4.2 New legislative initiatives create a framework for more transparency and sustainability in the acquisition of battery raw materials

- The extraction of raw materials for battery cell production largely takes place outside Europe, often in countries with **lower environmental and social standards**, as a result of which there often are environmental, social and economic challenges.
- Numerous legislative measures and initiatives on the part of the purchasing industry are aimed at a **sustainable extraction of raw materials**.
- Laws and regulations strengthen **due diligence**, creating legal clarity and enhancing companies' respect for human rights.

Technical innovations and sustainability standards mitigate the impact of raw material extraction

The extraction of raw materials for battery cell production largely takes place outside Europe, often in countries with lower environmental and social standards, and thus far beyond the reach of regulatory requirements in European countries. The supply chains for raw materials are partly non-transparent and often beyond the influence of the end users. As a highly developed industrial and export nation, Germany is dependent on a secure and sustainable supply of raw materials. At the same time, the public perception of battery raw materials is marked by human rights violations, environmental pollution and conflicts over resources. Very often the focus is on cobalt[141] in connection with human rights violations (cf. Annex 4.1.), lithium[142] in connection with high water consumption (cf. Annex 4.2) and graphite[143] in connection with environmental pollution (cf. Annex 4.3). But environmental disasters related to nickel[144] or copper[145] production also affect the image of batteries.

The environmental, social and economic challenges resulting from the demand for battery raw materials are complex and require specific consideration.

Cobalt

A large part of cobalt production (about 70%) takes place in the Democratic Republic of Congo, where it is mainly extracted as a by-product in copper mines. Although most of the mining is done in large industrial mines, a not insignificant part (about 10%) of the global cobalt production is extracted in small-scale mining („artisanal mining"). The high price of cobalt, the near-surface location of the ores containing cobalt and the lack of alternative earning opportunities for the local population make this form of mining attractive for many people in Central Africa. These are not always illegal mines. Small-scale mining is regulated by Congolese law and special areas have been designated for this purpose. The work there is usually done with the simplest tools. There are also reports of child labour, forced labour and desolate labour protection. Avoiding cobalt extracted under these circumstances, however, is not easy under current conditions. The mined ores are mostly bought by intermediaries and processed in cobalt smelters together with ores from other mines, which often makes it impossible to trace the ores.

In order to minimise reputational risks, secure access to valuable raw materials and not be directly exposed to the strong price fluctuations on the world market, many cell producers and car manufacturers have started measures to solve the multi-layered challenges of cobalt. Many OEMs have signed supply agreements with major mining groups to prevent cobalt from entering the group's supply chains from uncertified sources and to secure access to certified raw materials in the long term.[146] [147]

On behalf of a private initiative of BASF, BMW and Samsung, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ – the German Society for International

141 Frankel, 2016

142 Frankel & Whoriskey, 2016

143 Whoriskey, 2016

144 Spiegel, 2020

145 Board, 2017

146 Johannsen, 2020

147 BMW, 2020b

Cooperation) is implementing the pilot project „Cobalt for Development“ with the aim of sustainably improving the working and living conditions of people in small-scale mining.[148] VW has joined this initiative and is designing a certification system for cobalt smelters in cooperation with the Responsible Minerals Initiative (RMI).[149]

The Daimler Group is working with RCS Global to make the industry-recognised „Standard for Responsible Mining“ of the Initiative for Responsible Mining Assurance (IRMA) a key criterion for supplier decisions and contracts in raw material supply chains.[150]

Tesla publishes an annual Conflict Mineral Report Template (CMRT) outlining the efforts made to prevent human rights violations along the supply chain of the 3TG[151] conflict minerals and cobalt.[152] This publication is a regulatory requirement under the Dodd-Frank Act for companies listed on US stock exchanges.

Lithium

The world's largest known lithium reserves are located in a plateau known as the „Lithium Triangle“, which stretches across Chile, Argentina and Bolivia. These are generally lithium-bearing brines in the underground.

For lithium production, this brine is pumped to the surface. The water is evaporated in huge evaporation basins and the dissolved minerals are gradually precipitated. Since large amounts of brine are extracted from the underground in the process, there is a fear that freshwater from surrounding areas will run in and cause a serious drop in the groundwater level of the surrounding communities. This threatens the livelihoods of many people in the area, who are heavily dependent on agriculture, tourism and salt harvesting in the deserts. At the same time, lithium production requires few workers, so the local population does not participate through increased employment. The local communities generally benefit little from the increasing demand for lithium.[153] [154]

Due to the steadily increasing global demand for lithium and Australia's rapidly growing share of the world market, the Chilean government renegotiated the contracts for lithium mining between 2016 and 2018. Accordingly, the export of lithium carbonate is to increase from 80,417 tonnes in 2017 to 300,000 tonnes.[155] In the new contracts between the government and lithium producers, it was agreed to increase the use of new, water-saving technologies, such as water recovery through condensation of the evaporated water, pumping back the brine after lithium extraction, and membrane technologies for the direct separation of lithium from the brine.

At the same time, buyers are also increasing the pressure on lithium producers. BMW, for example, has announced that it will sign a contract with Livent for sustainably produced lithium. This company uses a process for lithium extraction in which the brine is pumped back directly into the ground after lithium separation. This is to avoid a drop in the groundwater level.[156]

In Germany, too, there are lithium deposits. For example, there are large lithium deposits in the form of thermal water/brine in the Rhine rift valley in southwest Germany. Initial estimates suggest that theoretically there is enough lithium in the ground for 400 million electric cars.[157] A pilot project at the Bruchsal geothermal power plant is to show whether lithium can be economically extracted here. About 800

148 Volkswagen, 2020b

149 Volkswagen, 2021a

150 Daimler, 2021

151 3TG stands for the minerals tin, tungsten, tantalum and gold.

152 Tesla, 2020

153 Boddenberg, 2020

154 Götze, 2019

155 Bürof, 2019

156 Benny, 2021

157 Witsch, 2021

tonnes of lithium per year could be extracted as a by-product of the geothermal power plant.[158] In order to eliminate legal uncertainties in the extraction of these resources, the new version of the German Mining Act was passed in 2021. As a result of the amendment, lithium in the form of brine is now also considered a non-minable mineral resource.[159] Previously, only lithium ore was mentioned in the legal text.[160]

In Serbia, the mining company Rio Tinto is working on the development of a large lithium deposit. In 2004, the company discovered a previously unknown sodium-lithium-boron-silicate-hydroxide mineral ($LiNaSiB_3O_7(OH)$) in the Jadar region, which is called „Jadarite" (after the Serbian region). According to initial findings, this mineral should serve as a suitable source of high-purity lithium carbonate in „battery grade" (> 99,5% Li_2CO_3). Borates (used for glass fibres, ceramics, etc.) and sodium sulphate (e.g. pharmaceuticals) are produced as by-products. The mineral resources in the Jadar region amount to 136 million tonnes, equivalent to 2.5 million tonnes of lithium carbonate (Li_2CO_3) or 21 million tonnes of borates (B_2O_3). This would correspond to an annual production of lithium carbonate of 55,000 tonnes – in comparison, 35,000 tonnes of lithium salt should be mined annually in the Salar de Uyuni project (ACI Systems).[161] With estimated lithium reserves of 17 million tonnes, the Jadar region is an important strategic location for the critical raw material lithium on the European continent in order to minimise raw material dependency, especially on politically unstable regions.[162]

Graphite

The majority of global graphite production from natural graphite deposits takes place in countries with comparatively low environmental standards. China is one of the largest producers of both natural and synthetic graphite. The production of natural graphite in particular can have serious environmental impacts if basic labour and environmental protection requirements are ignored. Although graphite is non-toxic, process-related dust pollution can lead to health problems both in the immediate working environment and in surrounding settlements. In addition, inorganic acids are sometimes used to purify graphite. If these are not sufficiently shielded from the environment, they can pollute the groundwater.[163]

An alternative is the use of artificial graphite. This is produced by heating coal and tar residues at high temperatures and long process times. This avoids the environmental impact of the mostly above ground mined and purified graphite. In addition, this separates production from the ore deposit and can, in principle, be set up anywhere in the world. The use of renewable raw materials as a carbon source is currently being researched. The CO_2 footprint of production depends largely on the energy mix used. The types of graphite used for batteries differ in terms of performance, price and quality (variations). In 2018, the market share of artificial graphite in lithium-ion batteries was around 50%.[164] (see also raw material profiles in the appendix)

The legal integration of due diligence obligations creates legal clarity and strengthens the observance of human rights

With an import volume of 1,104 billion EUR, Germany is one of the largest importing countries in the world after the USA and China and can thus exert a considerable influence on global supply chains. Until now, companies in Germany have been free to analyse human rights violations in their supply chains and initiate measures to implement the UN Guiding Principles on Business and Human Rights. A survey by the National Action Plan on Business and Human Rights in mid-

158 KIT, 2020

159 Non-minable means the freedom of any person wishing to mine non-minable mineral resources to do so, irrespective of whether he owns the land. Non-mining mineral resources become the property of the person entitled to them when the deposit is developed and extracted. The entire process is regulated by law and is subject to state supervision.

160 Deutscher Bundestag, 2021a

161 On 01 May 2021, the Bolivian government re-tendered the lithium mining concessions for the Salar de Uyuni (Greis, 2021).

162 RioTinto, 2021

163 Dolega et al., 2020

164 Whiteside & Finn-Foley, 2019; Whiteside & Finn-Foley, 2019

2020 showed that only 22% of the companies surveyed (with more than 500 employees) comply with the requirements.[165]

In order to regulate due diligence by law, the Federal Cabinet adopted the draft of a „Law on Corporate Due Diligence in Supply Chains“[166] on 03 March 2021, which will be adopted by the German Bundestag on 11 June 2021 as the so-called „Lieferkettensorgfaltspflichtengesetz – LkSG (Supply Chain Due Diligence Act) and will thereby come into force on 01 January 2023.[167] The aim of the law is for companies based in Germany to be responsible for complying with internationally recognised human rights in supply chains through due diligence. The responsibility extends to the entire supply chain, whereby the degree of responsibility in the supply chain is graded according to the degree of influence. The elements of due diligence apply accordingly to the company itself as well as to its direct suppliers. Human rights risks at indirect suppliers, on the other hand, must only be analysed and addressed when the company becomes aware of them.

The National Due Diligence Act will initially only apply to large companies with more than 3,000 employees in Germany from 2023 and will be extended to companies with more than 1,000 employees from 2024. Human rights violations and environmental risks, if they lead to human rights violations, will be covered as well as health and environmental hazards from mercury and persistent organic pollutants, which are part of two international agreements. The Federal Office for Economic Affairs and Export Control (BAFA) is to be entrusted with control and enforcement. In the event of violations, fines and periodic penalty payments can be imposed. In the case of serious violations, exclusion from public contracts is possible.

The proposal for a new EU Batteries Regulation addresses the due diligence of companies in the battery supply chain

The new Batteries Regulation proposed by the EU also addresses due diligence. The proposal includes requirements for the placing of batteries on the market to counteract human rights abuses and negative environmental impacts, as well as to ensure the supply of valuable raw materials.[168] Among other things, it is planned to introduce mandatory due diligence for raw materials in industrial and automotive batteries. The regulation states that this due diligence will in principle require verification by third parties via notified authorities. It also points out that numerous voluntary initiatives already exist, such as Responsible Mining Assurance (IRMA), Responsible Minerals Initiative (RMI) and Cobalt Industry Responsible Assessment Framework (CIRAF). However, voluntary efforts may not ensure that all economic operators placing batteries on the market comply with the same minimum requirements. Therefore, Article 39, together with Annex X, requires due diligence requirements to be made mandatory for rechargeable industrial batteries and batteries for electric vehicles.

For the implementation of due diligence, reference is made to internationally recognised standards, such as the ten principles of the UN Global Compact,[169] the UNEP Guidelines for a Social Life Cycle Assessment of Products,[170] the OECD Due Diligence Guidance for Responsible Business Conduct[171] or the OECD Due Diligence Guidance for Promoting Responsible Supply Chains for Minerals from Conflict and High-Risk Areas.[172]

Supply chain due diligence should take into account the most widespread social and environmental risk categories. This concerns current and predictable impacts on universal human rights, human health, the right to health, occupational safety, impacts on the environment, water use, soil protection, air pollution, biodiversity and community life.

165 Initiative Lieferkettengesetz, 2020

166 BMWi, 2021b

167 Deutscher Bundestag, 2021b

168 European Commission, 2020e

169 UN Global Compact, 2021

170 UN Environment Programme, 2009

171 OECD, 2018

172 OECD, 2019

In addition, mandatory minimum quotas for the collection of batteries, the recovery rates for recycling and the recycled content in new batteries are to be established in order to reduce dependency on primary raw material imports with negative environmental impacts.

The proposal thus addresses very wide-ranging sustainability issues in relation to raw materials and circularity. **Since access to the EU internal market is linked to the implementation of the regulation, the EU has created a very powerful instrument to change the battery industry and its suppliers sustainably.**

This is to be supported by new IT technologies, such as an electronic exchange system, which will create more transparency and facilitate the electronic exchange of data on batteries. The EU wants to implement such a system by 01 January 2026. Article 65 requires the introduction of an „electronic file" (a battery passport) linked to the EU electronic exchange system. These requirements should apply to all industrial and traction batteries (>2 kWh) placed on the market from 2026 on. The aim is to better inform consumers and end-users and to encourage a market shift towards more environmentally friendly batteries. In addition, economic actors in the field of second life and recycling are to be empowered to make informed business decisions. The European Commission wants to introduce a mandatory battery passport for industrial and traction batteries.[173]

2.5 Economic efficiency

- Already today, many **electric vehicles have more favourable user-side (TCO) costs** than comparable combustion (based) passenger cars.
- The **cost parity** of e-cars with conventional cars in terms of purchase price could be achieved as early as **between 2022 and 2024.**
- **Already now**, purchase premiums **partly** provide for **lower acquisition costs of electric vehicles** compared to combustion engines.
- **Battery pack costs** are expected to **decrease** by a further **up to 60% by 2030** compared to 2020 levels.

2.5.1 The cost comparison on the user and production side is increasingly in favour of battery-electric vehicles

Another aspect of sustainability in battery (cell) production is the cost of battery cells or systems. For a long time, battery-electric vehicles were (or were considered) more expensive than comparable vehicles with internal combustion engines. But is this or this assumption still true at all? In order to clarify this, **two aspects should always be considered** in a respective cost comparison: **(1) the user costs, i.e. the "total costs of ownership" (TCO)** and **(2) the manufacturer's costs.**

If we look at the total cost to the user (TCO) of electric vehicles, i.e. an accounting method that takes into account all the costs incurred for the investment and not only the acquisition costs, but also all aspects of subsequent use (energy costs, repair and maintenance), we see that many electric vehicles already have a more favourable TCO than comparable passenger cars with combustion engines.

Electric vehicles are currently still more expensive to purchase than vehicles with combustion engines, but cost parity is in sight

If we first consider only the pure acquisition costs, it becomes clear that the current list prices for battery-electric vehicles are mostly still noticeably higher than those of comparable combustion vehicles. The main reasons for this are the still higher production costs, which are mainly due to battery production.

However, current analyses predict that, in terms of purchase price, cost parity between electric vehicles and comparable conventional passenger cars will already be attainable between 2022 and 2024. This is due to the accelerated market ramp-up of electric vehicles and the associated learning and scaling effects in battery cell production.[174]

Purchase premiums are already partly responsible for lower acquisition costs of electric vehicles compared to combustion vehicles

In Germany, in June 2020, the bonus for buyers of electric cars (the so-called "Environment Bonus") was increased to up to 9,000 EUR by the end of 2021 as part of the federal government's economic stimulus package, which was launched as a result of the Corona crisis. This has not only

173 European Commission, 2020e

174 Thielmann et al., 2020

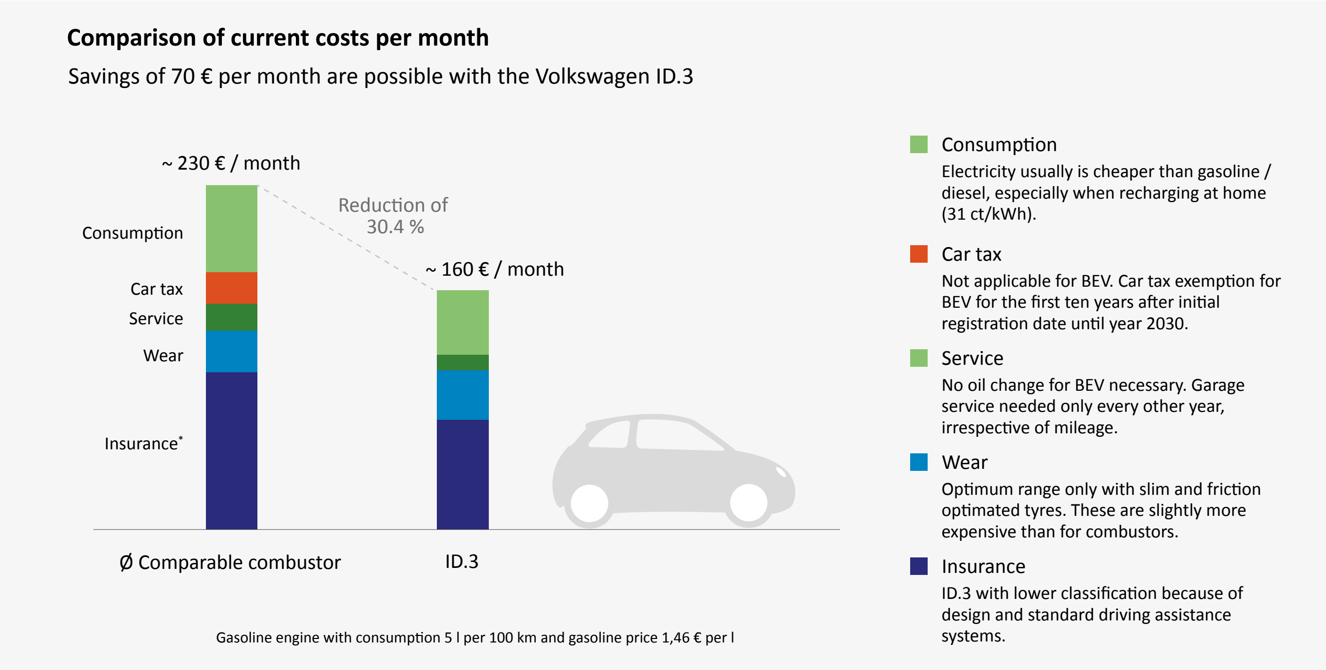


Figure 8: Comparison of running costs between e-car and vehicle with combustion engine, according to Volkswagen, 2020c.

significantly reduced the price difference between electric cars and cars with combustion engines, but has also led to some electric vehicles having lower purchase costs than comparable vehicles with combustion engines.[175] In spring 2021, for example, the basic version of the VW ID.3, minus the increased environmental bonus, already cost less than a comparable VW Golf with a gasoline or diesel engine.[176]

The consideration of all expenses is necessary for a true cost comparison

However, in order to arrive at the most comprehensive estimate possible of the user costs, a TCO analysis includes not only the acquisition costs but also *all expenses* incurred during use. This includes in particular

- Insurance costs,
- Vehicle tax,
- Expenditure on maintenance and repairs,
- Tyre wear,
- Fuel/electricity costs and
- A standard fee for the washing and maintenance of the vehicle.

A considerable part is also determined by depreciation, i.e. the sum spent on the purchase of a vehicle minus an average residual value of the car. There are numerous studies on this. For example, the ADAC carried out a comparison in July 2020. As a result, most of the electric vehicles (including hybrids) analysed were more favourable in terms of user costs than comparable gasoline or diesel vehicles.[177] A comparison of the TCO by The Mobility House of two comparable vehicle models of a manufacturer, once as an electric vehicle and

175 Verivox, 2020

176 ADAC, 2021d

177 As a basis for the calculations, an average holding period of five years with an annual mileage of 15,000 kilometres was assumed (among other things). In addition, fuel prices of 1.28 EUR for normal/super, 1.36 EUR for SuperPlus, 1.10 EUR per litre for diesel, 0.36 EUR/kWh for electricity, 9.5 EUR per kg of hydrogen, average standard rates for motor vehicle insurance (third-party liability and comprehensive insurance), current motor vehicle taxes and the current purchase premiums for electric vehicles and plug-in hybrids were taken as a reference (ADAC, 2021e).

once as a gasoline engine, led to similar results.[178] This is also shown by the comparison of the running costs of the VW ID.3 electric vehicle with a comparative combustion engine in Figure 8.

The production of electric vehicles has a high potential for cost reduction

Even if the TCO of electric vehicles is in many cases already lower than that of a comparable vehicle with an internal combustion engine, **the continuous reduction of production costs is an important step towards a sustainable cost advantage of electric vehicles** – especially since the government subsidy of the purchase price via the so-called Environment Bonus will not be granted permanently.

Manufacturer/production-side costs offer significant potential for reduction, especially in relation to the battery, which is currently one of the largest cost items, accounting for around 20-30% of the total cost of an EV. According to prognoses, battery pack costs will drop from 137 USD/kWh to 101 USD/kWh between 2020 and 2023 and are expected to drop to 56-58 USD/kWh by 2030 (see Figure 9).[179] The reasons for this are, in addition to scaling effects as a result of a corresponding increase in demand due to the global ramp-up of electric mobility, optimised cathode and anode materials (and thus higher energy densities) as well as further material and process innovations.[180]

With regard to economically and ecologically sustainable battery cell production, German and European manufacturers are increasingly striving for battery cell production in Europe. One of the reasons for this is that buying in cells usually means a cost disadvantage, no cell know-how can be built up and there is a dependency on delivery dates and cell quality.[181]

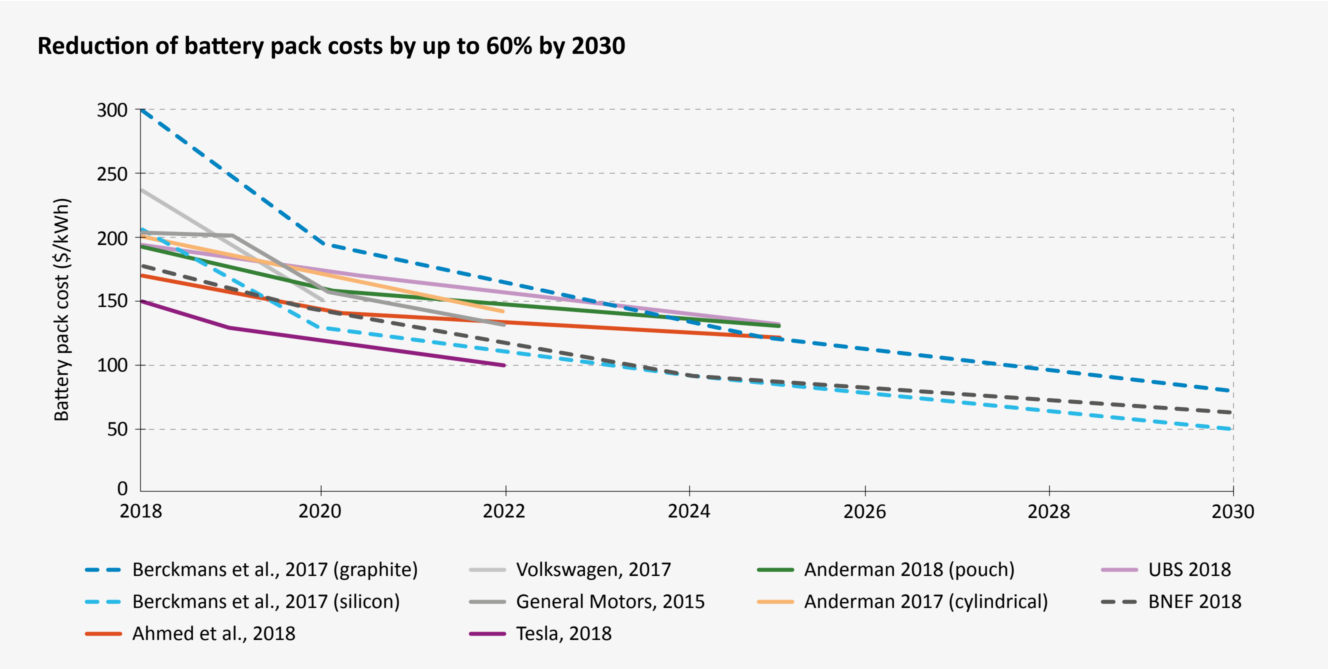


Figure 9: Predicted cost developments of battery pack costs until 2030 (according to Lutsey/Nicholas 2019).

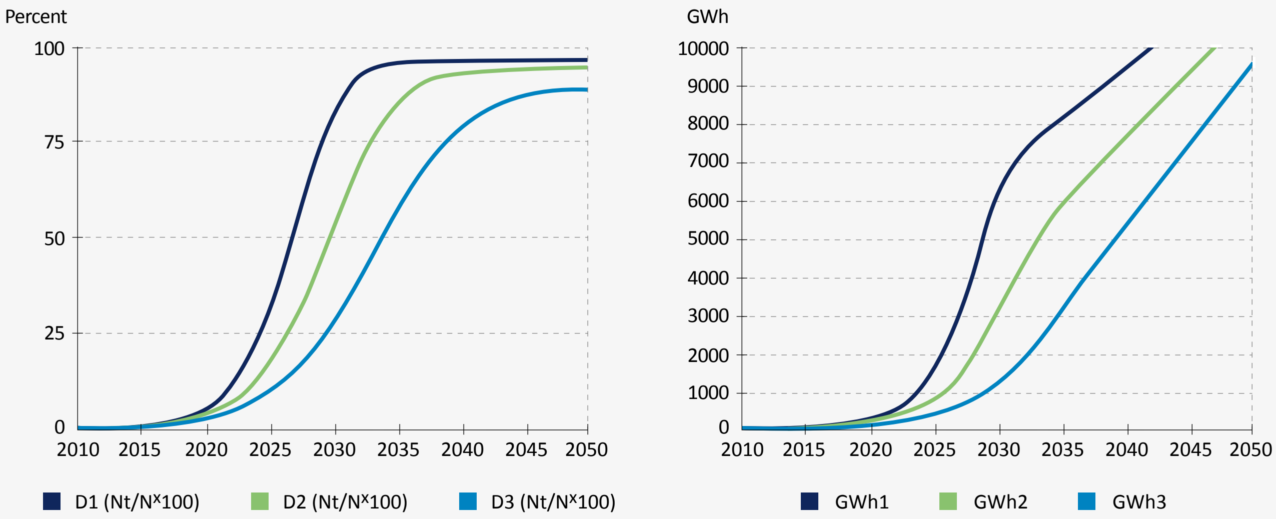
178 The Hyundai IONIQ Electric Trend was compared with the Hyundai i30 1.4 T-GDI Trend DCT, whereby the purchase price, the charging infrastructure for the electric vehicle, subsidies and tax breaks, fuel consumption, vehicle tax, vehicle insurance, maintenance, service and wear parts as well as the residual value were included as cost factors in the comparison. Overall, the electric version performed slightly better than the gasoline-powered version in terms of TCO (The Mobility House, 2020).

179 According to BNEF, the battery pack still accounted for around 21% of the total cost of an electric vehicle in 2020 (BNEF, 2020). According to Lutsey & Nicholas (2019), this share was around 30% in 2017 and was also estimated at 30% in 2025.

180 Thielmann et al., 2017

181 Köllner, 2019

Estimates of global new e-car registrations and LIB demand until 2050



Scenario D3/GWh3 in Figure 10 corresponds to the goals of the Paris Climate Agreement of 2015, Scenario D2/GWh2 leads to a much faster diffusion of e-cars with an (almost) complete global penetration already around 2040 and a global battery demand of 3 to 8 TWh between 2030 and 2040 and assumes external factors such as significant political measures (legislation, market incentives, electric vehicle quotas, combustion bans, etc.) that influence diffusion. Scenario D1/GWh1 (in turn) is based on the latest sales figures for BEVs and PHEVs and describes a development that is politically intended but at the same time supported by OEMs, in which an attractive electric mobility with a broad supply and growing demand progressively develops from a phase initially characterised by supply shortages and limited offers.[i]

i Thielmann et al., 2018

Figure 10: Estimates of global new e-car registrations in % and resulting LIB demand in GWh in each case until 2050, according to Thielmann et al., 2018.

Local production also benefits from secure demand due to established supply relationships, geographical proximity to customers and OEMs, and qualified personnel (cf. chapter 2.6.1). Competitive USPs could be created in the future through higher energy densities, fast-charging capability, lower costs and sustainable production, for example through the increased use of renewable energies.[182]

The establishment of European battery cell production is also stimulated by the current growth forecasts: Depending on the study, the share of e-cars in global new registrations is expected to be between 25 and 75% in 2030, which means a battery demand of 1 to 6 TWh per year (see also Figure 10).[183]

A particular argument in favour of European battery cell production is that the battery currently accounts for around 40% of the value added of an electric car,[184] with 60 to 80% of the value added to the battery system being determined by the cells.[185]

At the beginning of 2021, the annual production capacity in Europe was 30 gigawatt hours. In view of the enormous increase in battery demand, battery cell production in Europe has considerable potential for value creation. In addition, logistical and economic risks arise when large volumes for series production are delivered over long distances. Proximity to the production sites is therefore an

182 Köllner, 2021

183 Köllner, 2021; Thielmann et al. 2020; Thielmann et al., 2018

184 Volkswagen, 2019b

185 ElektroMobilität NRW, 2020

advantage. If one follows the predictions of the ramp-up of electric mobility,[186] then the currently announced production capacities for battery cells in Europe barely cover the future market requirements. For the future of electric mobility, the development and expansion of battery cell production in Europe is therefore of great importance in terms of economic and industrial policy.

This is particularly evident in the battery cell production sites already implemented, under construction or in planning in Germany and Europe. The most recent market analysis of the accompanying research for the battery cell production funding measure shows that the annual production capacity in Europe is expected to reach between 697 and 959 GWh in 2030 and that the share of production in Germany will be between 25 and 32%. In principle, such a massive expansion or build-up of production capacities can be expected to lead to strong economies of scale and a reduction in production complexity – with a corresponding effect on battery costs and thus on the manufacturing costs of electric vehicles.

New cell and manufacturing technologies as well as integration of the cells into the vehicle will lead to significant cost reductions

The US electric car manufacturer Tesla announced in autumn 2020 that it is possible to reduce battery system costs by up to 56% from current price levels by around 2024/2025 through improvements in cell design, the manufacturing process, electrodes and vehicle integration. This would achieve a price corridor of around 50 USD/kWh while increasing the range of electric vehicles by up to 54%.[187] VW also announced similar cost reduction targets in March 2021 with regard to battery systems, which are to be achieved in particular through the planned in-house production of the cells, the introduction of a so-called unit cell from 2023 on, optimisation of the cell type, innovative production methods and the consistent recycling of the cells.[188]

Battery innovations not only reduce costs, but also increase the ease of use and acceptance of electric cars

In addition to the predicted significant reduction in the costs of battery cells in particular, technological advances also contribute to an increase in the range of electric vehicles and thus increase their ease of use. Mercedes, for example, has announced ranges of up to 770 kilometres (according to the WLTP cycle) and reduced charging times of around half an hour for 80% battery capacity (or 15 minutes for 300 WLTP kilometres) with the EQS, the first model based on the EVA electric platform developed in-house.[189] E-car designer Lucid also talks of similar ranges with regard to its Air model, which is said to be able to travel up to 832 kilometres on one battery charge and recharge 300 miles (482 kilometres) of power in just 20 minutes via a 900-volt system.[190]

The significantly improved user-friendliness that can be expected as a result, due to significantly greater ranges and shorter charging times, should also have a positive effect on the acceptance of electric vehicles. However, the so-called „range anxiety“ is mostly unjustified anyway: Only slightly more than one percent of car journeys are further than 100 kilometres (even though car drivers often include expectations of long-distance car use when deciding to buy a vehicle). In addition, range anxiety is being countered by the development of more powerful and fast-charging batteries as well as the expansion of public charging points. The German government has set itself the target of one million charging points by 2030, for a predicted ten million e-cars in Germany by then. It is not certain how many publicly accessible charging points will be necessary in the future, since on the one hand, faster charging processes mean that more vehicles can be served at a charging point per day, and on the other hand, a large proportion of charging processes will continue to take place at home in future. Especially since the costs for the charging system at home (wallbox) have been subsidised by the federal government with 900 EUR since November 2020, which in many cases covers the majority of

186 According to a study by Ernst & Young, up to 40 million electric vehicles (incl. PHEVs) are expected in Europe by 2030 (Colle et al., 2021). The EV Outlook of the IEA expects around 13 million new registrations of electric vehicles (incl. PHEVs) per year in Europe in 2030 (IEA, 2021).

187 In terms of cell design, Tesla plans to introduce a new round cell (4680) with six times the power and five times the energy output of a current Tesla cell while accelerating the production process. This in turn should allow for a significantly higher annual output of cells. In addition, the cell chemistry will use silicon in the anode, which should further reduce cell costs. With regard to the cathode, cobalt is to be dispensed with, which should also save costs. In addition, the start of in-house recycling of lithium-ion batteries in Nevada has been announced for 2021 (Schaal, 2020f; P3, 2020).

188 Volkswagen, 2021b

189 Schaal, 2021a

190 Schaal, 2020g

the costs for purchase and installation. This subsidy is in high demand among e-car drivers. Between the end of November 2020 and the end of March 2021 alone, a total of 377,500 applications for subsidies for a private charging station were submitted.[191 192]

2.6 Employment

2.6.1 Battery (cell) production compensates for the decline in employment in the automotive industry

- The automotive industry is in a process of **profound transformation** and is challenged by sharp declines in sales as a result of the Covid 19 pandemic
- Particularly due to declines in demand in the domestic market and job-saving technical.
- advancements in manufacturing, the **number of employees** in the automotive industry in Germany is expected to **decline** in the short and medium term.
- The transformation of the automotive industry is leading to a **reorganisation of value creation** and a shift in the demand for labour in the automotive industry.
- Numerous **new jobs** are being created in battery cell production, which entail a high qualification requirement.

The automotive industry is of great importance for prosperity and employment in Germany, but is in a state of change

In 2019, the companies in the German automotive industry generated a turnover of just over 436 billion EUR and employed around 847,600 people directly.[193] Taking into account the 643,000 employees in the secondary market, for example for spare parts (aftermarket) and in the trade, as well as the 654,000 employees at suppliers in other sectors and in the service sector, the automotive industry employs a total of 2.2 million people (about seven percent of jobs subject to social insurance contributions in Germany), making it the country's strongest industrial sector in terms of employment.[194]

Declining production figures in Germany since 2016, especially for vehicles with diesel engines, the current transformation of production towards connected, autonomous, shared and electric (CASE) vehicles and, last but not least, the global decline in sales as a result of the Covid-19 pandemic are causing job transformations. In 2019, around 11,000 jobs have already been cut in the German automotive industry (-1.3%). In July 2020, 801,653 people were employed in the automotive industry, a further decline of 2.6% (21,220 jobs) within only eight months.[195]

The number of employees in the German automotive industry will continue to decline

The automotive industry is in a profound transformation process and was already confronted with disruptive trends such as electric mobility, autonomous driving, highly automated factories and shared mobility before the Covid-19 pandemic. According to research by Capgemini, automotive companies increasingly value the following three aspects as crucial for their future in addition to CASE: sustainability, customer centricity and smart industry.[196] Companies are aware that they have to produce modern, sustainable vehicles and at the same time position themselves in a mobility ecosystem.

Since 2019, the Corona pandemic has created an additional challenge for the automotive industry. In 2020, global sales of passenger cars plummeted and their global production fell by 17% as a result.[197] In Europe, sales figures fell by about 25% in 2020. Similarly, the production of passenger cars in Germany also declined. With a good 3.5 million vehicles,

191 Götz, 2021

192 Nobis & Kuhnimhof, 2018

193 Falck et al., 2021

194 BMWi, 2021c

195 BMWi, 2020a

196 Winkler & Mehl, 2021

197 Statista, 2021

the production of German manufacturers in 2020 for the domestic market was 24.6% below the previous year's value.[198] Exports also fell by 24% compared to the previous year to 2.6 million passenger cars in 2020. Nevertheless, the domestic and export production of German car manufacturers was also declining before the pandemic. In 2019, the production volume was about 75% (domestic) and 79% (export) of that in 2016.

Due to the current strong sales growth in China, the industry is slowly recovering from the crisis-related sales decline.[199] In the coming years, demand for individual mobility solutions will continue to rise, according to a recent analysis by Roland Berger.[200] By 2030, the volume of passenger cars and light commercial vehicles sold worldwide is expected to be 15% higher than at present. However, this growth will be driven primarily by Asian markets, especially China (+32%). Both Germany and Western Europe, the most important export market for the German automotive industry, will see a decline in demand for passenger cars.[201] Despite the slow recovery, the domestic production figures of German passenger car manufacturers were again below the level of the first quarter of the previous year in the first quarter of 2021, at 8% (domestic) and 9% (export).[202]

As a result of the significant decline in production, but also in particular due to job-saving technical advances in manufacturing, the number of employees in the automotive industry in Germany is expected to decrease in the short and medium term. Digital technologies in production, the automation of repetitive manual tasks and automated and driverless transport vehicles in logistics will reduce the demand for labour. According to an analysis based on data provided by VW, for example, the average demand for employees in vehicle production (at VW) will fall by 12% by 2029 due to job-saving technological progress alone.[203] This increase in efficiency in process and site-specific factors is fundamentally independent of the drive technology of the vehicles to be produced, but can be implemented more quickly due to the less complex processes in the production of BEVs.

In the longer term, trends such as shared mobility and driverless mobility services will lead to a further decline in demand for passenger cars and thus to a further reduction in jobs in the German automotive industry.[204] According to Hagedorn et al., the introduction of automated driving functions in combination with shared mobility concepts will lead to a change in both the demand for passenger kilometres and the modal split. In all scenarios studied, there will be a shift from kilometres travelled in private cars to those travelled via sharing concepts by 2030 – a trend in usage behaviour that is also expected by McKinsey. Even before the Corona crisis, 6% of baby boomers (the generation born between 1945 and 1965) expressed a preference for rental and ridesharing products. In Generation Y, i.e. those born in the period from the early 1980s to the late 1990s, the share is already 34%.[205]

The transformation of the automotive industry is leading to a reorganisation of value creation and a change in labour requirements

In the German automotive industry, 49.8% of jobs (around 422,100) are currently directly related to the production of internal combustion engine vehicles (ICEVs). Based on the future share of low-emission vehicles in total production that will be necessary to comply with the EU fleet limits, the ifo Institute has estimated that between 147,700 (17.4%) and 198,400 (23.4%) jobs in the automotive industry will be lost by 2030 as a result of the corresponding decrease in the production of ICEVs (visualisation in Figure 11).[206]

198 VDA, 2021a

199 Manager Magazin, 2021

200 Bernhart & Mogge, 2021

201 Hagedorn et al., 2019

202 VDA, 2021a

203 Herrmann et al., 2020

204 Hagedorn et al., 2019

205 Hofstätter et al., 2020

206 Falck et al., 2021

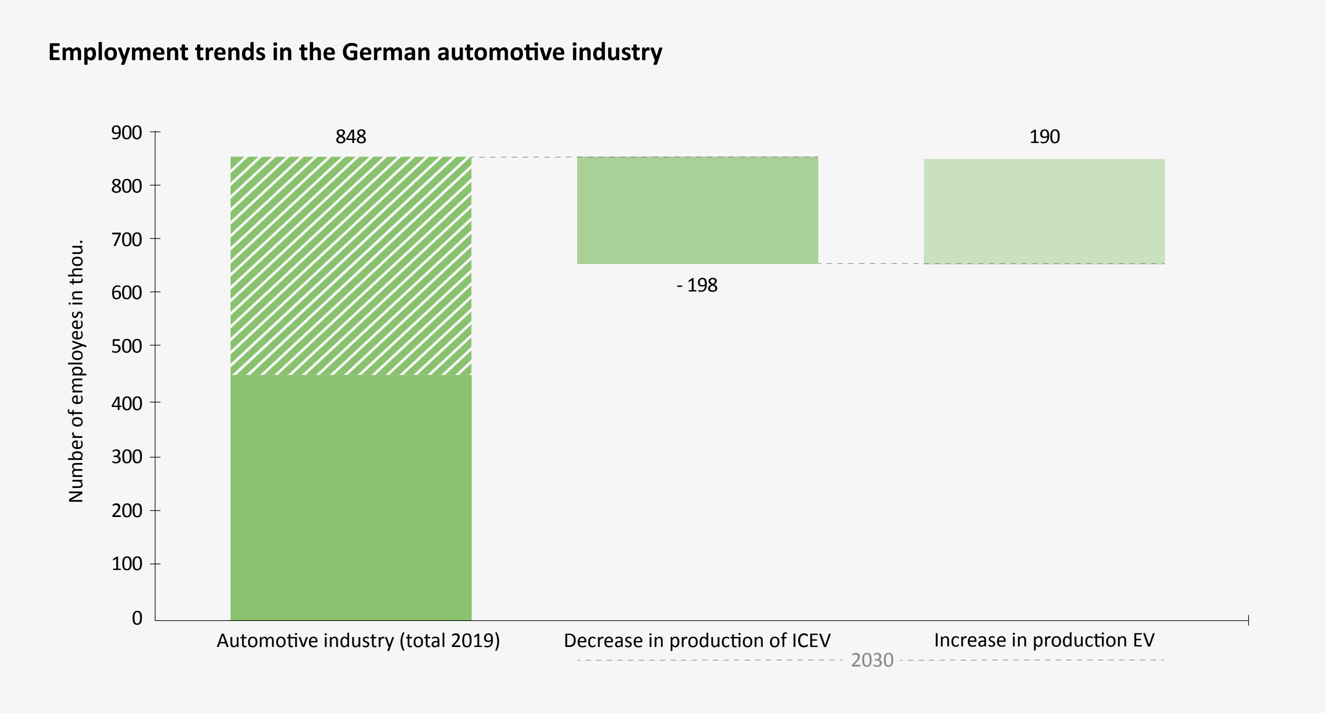


Figure 11: Balance of employment in the automotive industry starting from about 848 thousand employees in 2019, of which about 422 thousand are directly related to the production of vehicles with combustion engines (shaded area). Decrease by 2030 based on ifo Institute estimate due to increase in EV share to 47%. Increase based on the Boston Consulting Group's finding that the production of BEVs currently requires about 4% fewer working hours at OEMs. Own representation according to Falk et al., 2021 and Niese et al., 2021.

No information is given on the number of jobs needed to produce the estimated 35 to 47% low-emission vehicles.

A recent comparison of all stages of vehicle production conducted by the Boston Consulting Group shows that the production of BEVs basically requires only slightly less workforce than that of a comparable ICEV, with about 1% fewer working hours.[207] However, the production of battery cells and power electronics is currently not carried out by car manufacturers, but by suppliers. As a result, there are about 4% fewer working hours on the OEM side in the production of BEVs (cf. Figure 11). In the event that OEMs produced all powertrain and power electronics components, including battery cells, themselves, labour hours per vehicle would increase by 7 percentage points, according to the study.

In order to maintain employment and the associated prosperity, a large part of the value added in the production of vehicles must continue to take place in Germany. Up to now, central components of electric vehicles such as batteries (cells) have largely been imported.[208] If Germany were able to supply the market more strongly with both domestically produced BEVs and domestically produced traction battery cells, a positive growth and employment effect could certainly be achieved in the long term as well.[209]

An analysis by the NPM of the possible effects of electric mobility on employment in Germany underlines the urgent need for action. It concludes that the effects on employment structures will be significant if the competitive situation of German industry in the field of electric mobility does not improve in the coming years and the import demand for

207 Küpper et al., 2020

208 NPM, 2020

209 Mönnig et al., 2018

battery cells and electric vehicles continues to grow with the market ramp-up.[210]

The market ramp-up of electric vehicles creates a large number of new jobs

Despite the sharp decline in car sales in Europe in 2020 due to Corona, the total number of electric cars (battery-electric, BEV and plug-in hybrid, PHEV) sold in Europe in the same period more than doubled. Not least due to the EU fleet limit value, the supply of electric cars has also increased significantly recently. According to manufacturers, this trend will continue.

Induced by the market ramp-up of electric vehicles, global demand for batteries, especially lithium-ion batteries, has increased from over 20 GWh in 2010 (almost exclusively for consumer applications) to about 250 GWh in 2020 (over 70% of which is for electric vehicles) and is expected to increase to at least 2-3 TWh in 2030.[211] The latest market analysis by the accompanying research for the battery cell production funding measure shows that the annual production capacity in Europe in 2030 will be between 697 and 959 GWh and that the share from production in Germany will be 25 to 32%.[212]

According to the Sustainable Battery Value Chain Report, the World Economic Forum (WEF) expects a total of 10 million jobs to be created in the battery value chain worldwide by 2030.[213] Various studies estimate the direct demand for employees resulting from the establishment of a production plant with an annual production capacity of 32 GWh at 2,900 and 5,800 and about 3.7 to 7.5 times more indirectly along the battery value chain.[214] [215] Converted, this results in 90 to 180 direct jobs in battery production per GWh and 350 to 1,400 indirect jobs along the battery value chain. A calculation carried out by Fraunhofer ISI resulted in a maximum of 90 direct and over 400 indirect jobs for low-capacity production. Their calculations for a scaled battery production of about 1,000 GWh (possible annual production capacity in Europe in 2030) result in about 250 direct and indirect (upstream) jobs per GWh.[216] In relation to the annual production capacity in Europe in 2030, this means that around 175,000 to 240,000 jobs will be created.

As an example, the following new jobs will be created in Europe by 2030 in the area of the central battery component for BEVs:

- Around 72,000 new jobs in cell manufacturing and battery production.[217] Numerous large-scale cell factories have already been announced or are under construction.
- New jobs in the processing of raw materials. According to Roland Berger, there is currently no value creation in Europe at the active material production stage. However, several investments in this area have already been announced.[218] BASF, for example, is currently building a cathode production facility, which, according to the IHK, will create up to 200 new jobs in a first step.[219]
- Recovery of secondary raw materials through recycling. For every thousand tonnes of lithium-ion battery waste, about 15 jobs will be created for the collection, dismantling and recycling of these batteries. This will create up to 6,500 jobs in Europe by 2030.[220]

The Strategic Research Agenda for Batteries 2020 highlights that the right skills are essential to develop and strengthen a highly skilled workforce along the entire battery value

210 NPM AG4, 2020

211 Thielmann et al., 2021

212 VDI/VDE-IT, tbp

213 World Economic Forum Report, 2019

214 NPE, 2016

215 JRC, 2017

216 Thielmann et al., 2021

217 Platform EM, 2020

218 Roland Berger, 2018

219 RBB, 2020

220 Platform EM, 2020

chain and address the most pressing skills gaps.[221] Such gaps are, for example, the retraining of employees working in industries and areas that will disappear or be replaced in the future (e.g. around the combustion engine), or the upskilling of employees in industries working along the battery value chain and facing the challenge of integrating digitalisation (e.g. automation, autonomous systems for R&D, processes, production) and systemic thinking in the value chain, e.g. to develop competitive and sustainable products for a circular economy. Crucial for future employment in the automotive industry and along the battery value chain is to recognise this change in employment and the resulting great importance of vocational training and to put strategic human resources planning into practice. The urgency is evidenced by the quote: “Currently, our labour market cannot sufficiently meet the demand,” said Maroš Šefčovič, Vice-President of the EU Commission and Commissioner for Interinstitutional Relations and Foresight. According to industry estimates, there could be a shortage of around 800,000 skilled workers along the entire production chain by 2025.[222]

221 Batteries Europe, 2020

222 European Commission, 2021a

3 CONCLUSION

Batteries are a decisive key technology for a sustainable transformation of mobility and energy supply. Nevertheless, battery technology still has clear potential for optimisation with regard to the sustainability topics analysed.

Climate protection: Battery production is energy-intensive. As a result, the current production of battery-electric vehicles emits more greenhouse gases than the production of comparable vehicles with combustion engines. However, the continuous development of battery technology has already led to a reduction in production-related greenhouse gas emissions. On the other hand, the consistent use of renewable energies in battery cell production will result in a further significant reduction in emissions in the future. In the use phase (well-to-wheel), battery-electric vehicles are characterised by low greenhouse gas emissions and very high energy efficiency. This applies to the comparison with vehicles with both combustion engines and fuel cell drives. Therefore, battery technology benefits from the global agreement on binding measures to protect the climate. This policy is intended to price in the damage caused by climate change and to create incentives for more sustainable behaviour. In concrete terms, this policy is reflected, for example, in the European and national emissions trading systems, in the European fleet limits or in the fuel-specific taxation of motor vehicles and fuels.

Industrial policy: With battery cell production, a new branch of industry is currently being established in Europe. In order for this to be viable for the future, existing strengths must be pooled. Europe, and Germany in particular, have considerable expertise in mechanical and plant engineering as well as a competitive research landscape in the fields of manufacturing technology and electrochemistry. European and national networks such as the European Battery Alliance, ETIP BatteRIes, Battery 2030+, LiPLANET and several others have been established to connect the actors of the European battery ecosystem. In this way, cooperation and knowledge exchange are strengthened. Public funding programmes provide incentives for the development of innovative and sustainable battery technologies “Made in Europe”. In the two Important Projects of Common European Interest (IPCEI) funding measures alone, 12 EU member states are awarding up to 6.1 billion EUR in funding to more than 50 companies, which will as a result invest a further 14 billion EUR in the development of the battery value chain.

Circular economy: High-volume battery production increasingly requires more raw materials and the development of new raw material sources. In order to keep the impact on nature as low as possible, the required battery raw materials must be used efficiently and transferred into a resource cycle. Second-life applications, which can significantly increase the useful life of batteries and thus their value retention, have a particularly positive effect on efficiency. In addition, research and industry are working on the development of recycling processes that automatically dismantle spent batteries and recover up to 95% of the raw materials they contain in reusable quality. With the EU Batteries Regulation proposal, the EU is creating the necessary framework conditions for the development of a battery recycling economy. As a result of the increasing spread of electric mobility, the return of used batteries will rise. This will enable economies of scale that will make the extensive recycling of battery raw materials economically attractive.

Raw materials governance: Battery raw materials are currently partly extracted in countries with low environmental and social standards. In future, both the supply of raw materials and compliance with sustainable environmental and social standards must be ensured throughout the entire supply chain. On the one hand, new technologies are being developed to reduce the environmental impact of raw material extraction. On the other hand, critical raw materials are increasingly being substituted through advances in battery development. For example, the weight proportion of cobalt in modern NMC 811 cells has already been reduced by 70% compared to NMC 111 cells. In addition, the Batteries Regulation proposed by the EU calls for extensive transparency in the raw material supply chain. As a result, tools are already being developed by the industry to track battery parameters and compliance with standards. One example is the Global Battery Alliance’s digital battery passport.

Economic efficiency: If no government subsidies are used, battery-electric vehicles are usually still more expensive to purchase than comparable vehicles with internal combustion engines. However, battery-electric vehicles already achieve cost parity, especially when the comparison is made on the basis of life cycle costs. In the future, battery-electric vehicles will be economically viable in more and more applications. Unlike vehicles with internal combustion engines, battery-electric vehicles still have considerable cost reduction potential, especially on the production side. For example, battery costs will more than halve by 2030 if the current learning curve is continued. This is on the one hand based on economies of scale in battery production and on the other hand on an increase in the performance of batteries.

Employment: Due to productivity gains, a reorganisation of value creation and a strong change in the after-market business, there is a decline in traditional jobs in the automotive industry. With consistent investment in battery production and electric mobility, this decline can be largely compensated for by a shift in the demand for labour. Along the battery value chain alone, several 10,000 new jobs will be created in Germany. The change in the qualifications required is creating a considerable need for qualifications. Industry, educational institutions and policy-makers must jointly address this challenge and create new needs-based education and training opportunities.

If the remaining challenges can be overcome, battery production will create a strong, future-oriented industrial sector in Germany and Europe. Its success depends not least on whether suitable framework conditions can be found that reconcile all the requirements for sustainability as well as maintaining the competitiveness of the European battery industry. The first steps on this path have already been taken. Many more will follow.

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4 APPENDIX – RAW MATERIALS PROFILES

4.1 Cobalt

What are the relevant characteristics of the raw material?
Cobalt (Co) is a silver-grey metal and is placed between iron and nickel in the periodic table. Due to its special properties (ferromagnetism, hardness and wear resistance in alloys, high melting point, low thermal and electrical conductivity, as well as its valence electron structure with which intense blue colours can be produced) cobalt is used in a wide variety of applications.

What is it needed for?
Cobalt is an important component of many lithium-ion accumulators and is used in the cathodes as an oxide (**l**ithium-**c**obalt **o**xide, **LCO**) or as a mixed oxide (**n**ickel-**m**anganese-**c**obalt, **NMC**, or lithium-**n**ickel-**c**obalt-**a**luminium oxide, **NCA**). In 2020, about 50-60% of the globally produced cobalt was used in batteries. The remaining cobalt was mainly used in superalloys, carbides, diamond tools and magnets.

How critical is the raw material?
Cobalt is mostly extracted as a by-product in copper or nickel mine production. The Democratic Republic of Congo currently dominates cobalt mine production with about 70% market share. In Europe, known cobalt reserves exist in Finland. However, the share of global production here was only 0.8% at last count. Refined cobalt production is concentrated in China, Finland, Canada, Japan and Australia.

Even though cobalt is not classified as a conflict mineral, it still presents similar risks due to the framework conditions of artisanal mining in the Democratic Republic of Congo. While the supply chain risk can be addressed in the context of due diligence, the high country risk remains due to the focus on Congo.[223] Figure 12 shows the nine largest cobalt mine producers including reserves by country. These represent about 93% of the world's cobalt mine production. To visualise the country risk, colouring is based on the average of the six World Governance Indicators[224] of the World Bank.

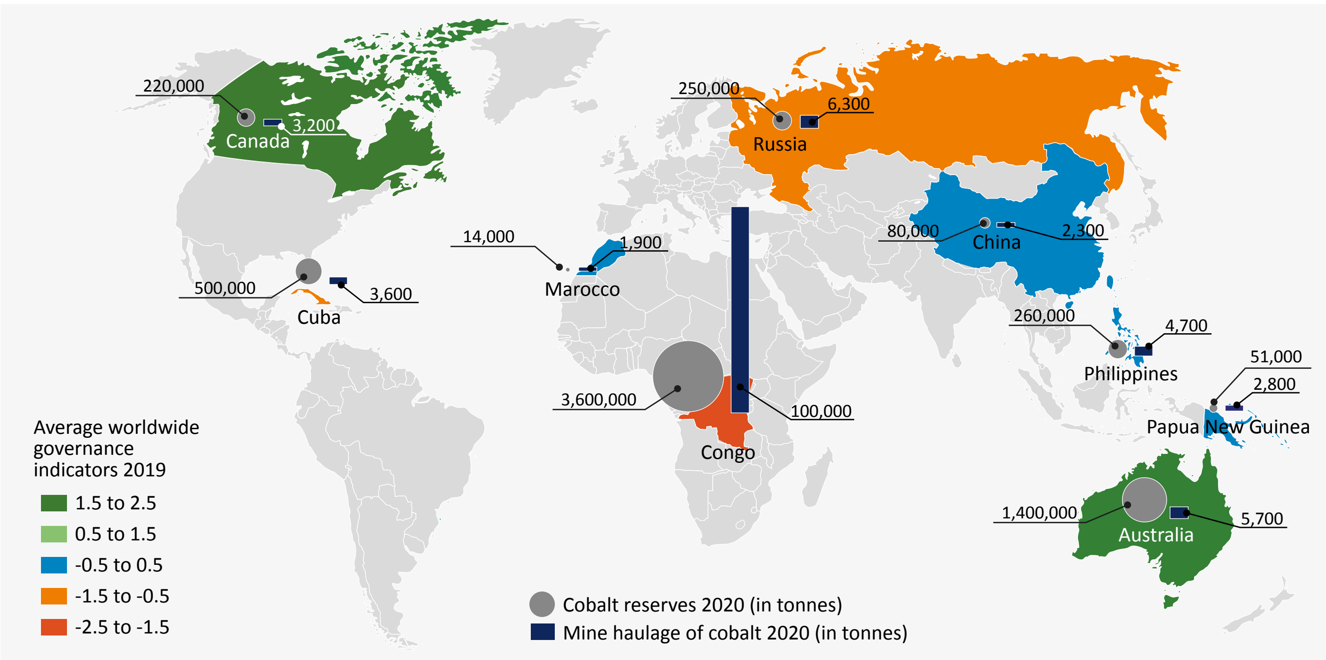

Figure 12: Cobalt production and reserves by country (2020). Shown in colour is the World Bank's World Governance Index (average) (2019). Own presentation according to Schütte, 2021; USGS, 2021a and Worldbank, 2021.

223 Al Barazi, 2018

224 Indicators: Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law und Control of Corruption.

Cobalt cannot currently be substituted in batteries without a loss of performance. Nevertheless, battery cells without cobalt have a significant market share, mainly due to their lower price. Batteries based on lithium iron phosphate (LFP) are expected to reach a market share of 25% in 2021.[225] At the same time, intensive research is being conducted into cobalt-reduced cathodes and cobalt-free cathodes.

How long do the known resources last?
Global reserves of cobalt were estimated at 7.1 million tonnes in 2020 by the U.S. Geological Survey (USGS). This amounts to 50 times the production volume in 2020. Global resources in copper and nickel-bearing sedimentary rock are estimated at 25 million tonnes. Another 120 million tonnes of cobalt reserves could be found in manganese nodules at the bottom of the Atlantic, Indian and Pacific Oceans.[226] Due to the high price of cobalt, the recovery of cobalt by recycling batteries is already economical today.

Is the supply of the EU guaranteed?
The EU is dependent on imports. On the positive side, Finland has cobalt reserves as well as refining capacities.

Is raw material extraction sustainable and compliant with human rights?
The Democratic Republic of Congo currently accounts for a large part of the world's cobalt mining. Historical smelting activities have damaged the ecosystem. Corruption is often a problem in the awarding of mining concessions. Artisanal mining in Congo brings risks of occupational safety and child labour.

4.2 Lithium

What are the relevant characteristics of the raw material?
Lithium is the lightest metal in the periodic table and has a high specific electrical capacity (3.86 Ah/g) and a very low electrode potential (-3.04 V relative to the standard hydrogen electrode). These properties make lithium the ideal material in modern batteries, especially for high energy density applications.

What is it needed for?
Lithium is an essential component of all lithium-ion batteries and is found there in the electrolyte as well as in the cathode (in discharged state). A battery cell with the cathode material NMC 111 and a cathode content of 35 wt% contains about 2.5 wt% lithium. In 2020, just under 71% of the lithium produced worldwide was used for accumulators. Lithium is also used in the ceramics and glass industry (14%), lubricants (4%), polymers (2%), metal casting (2%) and air purification (1%).

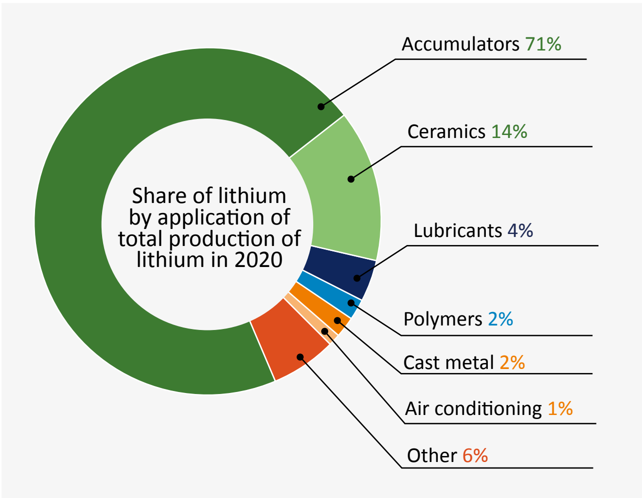

Figure 13: Use of lithium by application in 2020, according to USGS, 2021b.

225 Shang, 2021

226 USGS, 2021a

How critical is the raw material?

In recent years, Australia has become the largest exporter of lithium. Lithium is extracted there from solid rock in open-cast mines. As lithium concentrate, a large part of the exports goes to China, where it is further processed into battery precursors and battery cells. Chile and Argentina are the second and third largest suppliers of lithium. Here, lithium is extracted from brine and mostly processed locally into lithium hydroxide or lithium carbonate. Together, these three countries account for 90% of global lithium production. The three largest lithium producers, Albermale, SQM and Tianqi, produced around 50% of the lithium traded worldwide in 2019. This represents a high country as well as company concentration. [227]

The sharp rise in the price of lithium in 2016 triggered numerous investments, as a result of which production capacities were expanded. It can be assumed that enough lithium can be produced despite rising demand. The high country concentration will not change in the short term. Figure 14 shows the seven largest lithium mine producers and the countries with the largest lithium reserves. These seven countries represent about 99% of the world's lithium mine production. To visualise the country risk, the average of the six World Governance Indicators[228] of the World Bank is used for colouring.

Substitution in lithium-ion batteries is not possible. Battery technologies with other light alkali and alkaline earth metals

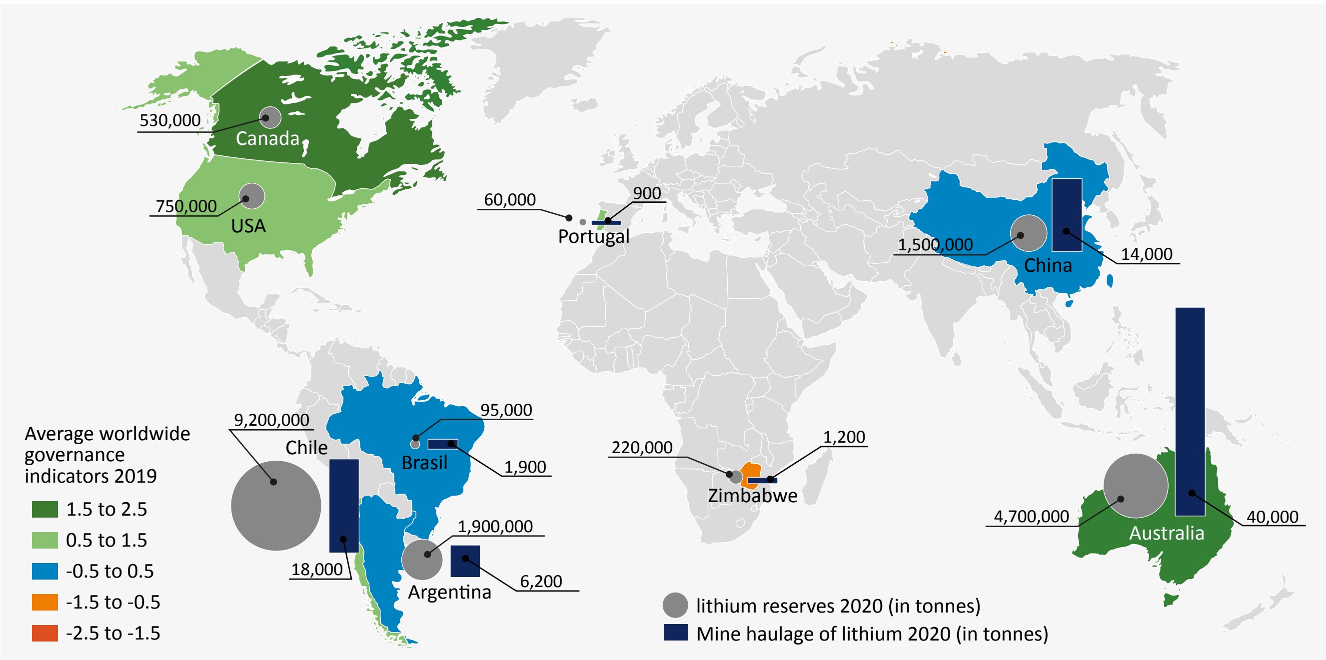

Figure 14: Lithium production and reserves by country (2020). Shown in colour is the World Bank's World Governance Index (average) (2019). Own representation according to Drobe, 2020; USGS, 2021b and Worldbank, 2021.

227 DERA, 2021

228 Indicators: Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law und Control of Corruption.

(sodium or magnesium) are currently being researched or used in niche applications (e.g. Na/NiCl2 batteries). [229]

How long do the known resources last?

Global lithium production in 2020 was 82,000 tonnes. The world's known lithium reserves are currently estimated at 21 million tonnes. This corresponds to 256 times the production volume in 2020. The information on the global resources is sometimes far apart. According to information from the American USGS from 2021, the global resources are around 86 million tonnes.[230] The demand for lithium is expected to increase by a factor of 50 by 2050 compared to 2018. This corresponds to an annual demand of about 19.5% of today's known reserves, or 5% of today's known resources. The extraction of lithium through the recycling of batteries does not yet play a major role in the supply of raw materials.

Is the supply of the EU guaranteed?

The EU is currently greatly dependent on imports. However, Europe has its own resources (Jadar, Serbia,[231] Upper Rhine Gorge in southern Germany,[232] Zinnwald project[233] in the Erzgebirge), which are currently being explored.

Is raw material extraction sustainable and compliant with human rights?

The raw material extraction of lithium takes place mainly in countries with a high governance index (Australia, Chile and Argentina) and mostly in sparsely populated areas. Nevertheless, conflicts with the population regarding water use are very prominent.

4.3 Graphite

What are the relevant characteristics of the raw material?

Graphite is an allotropic form of carbon. It can be extracted as ore (natural graphite) or can also be produced synthetically.

What is it needed for?

Graphite is currently mainly used for refractory materials, e.g. crucibles, covers in furnaces or as electrodes for electric steel, and as a lubricant. High-purity graphite is currently the standard material for the anodes in lithium-ion batteries. Graphite has very good electrical conductivity, is very stable even in highly oxidising environments and has the ability to store (charge) and release (discharge) lithium in a highly reversible manner. Graphite makes up about 14-19 wt% of a battery cell.[234]

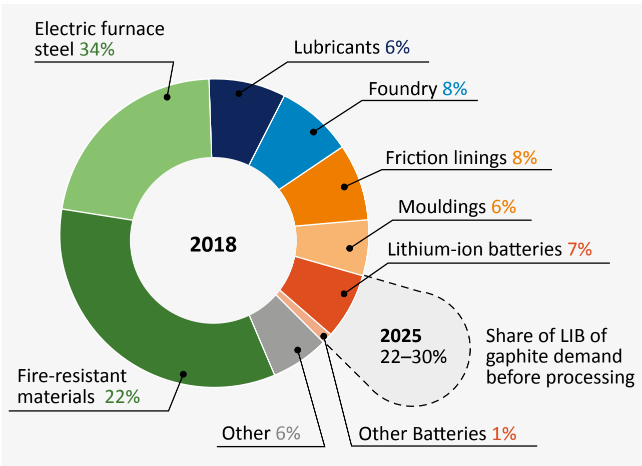

Figure 15: Use of graphite globally, according to DERA, 2021.

229 Fraunhofer IKTS, 2021

230 USGS, 2021b

231 RioTinto, 2021

232 Schneider, 2021

233 Deutsche Lithium, 2021

234 Damm & Zhou, 2020

How critical is the raw material?

The raw material graphite is critical for European battery manufacturers due to the high market concentration in a few large Chinese and Japanese companies and the lack of substitution possibilities. Total graphite supply is considered sufficient and graphite raw material production is expected to be able to meet future demand.

Known graphite reserves are spread around the world and are estimated at about 300 million tonnes of mineable reserves. About 24% of these are located in China. Large reserves are also located in Turkey (30%) and Brazil (25%). With about 1.05 million tonnes, European reserves account for less than 1% of global reserves. The resources in Europe are estimated at 11 m tonnes. China plays a dominant role in the production of natural graphite. China accounted for almost 70% of global production of natural graphite and 50% of synthetic graphite in 2018.[235] 95% of the graphite raw material is processed into the battery material graphite in China and Japan.[236]

The substitution possibilities are limited. For niche applications, graphite can be replaced by lithium titanium oxide (LTO). However, this is usually associated with higher costs and lower energy densities. Substitution with silicon is being investigated in research. At present, however, silicon can only be added to the graphite to a small extent (about 5-10%). The anodes of solid-state batteries are made of lithium metal and therefore do not require graphite, but these are still many years away from market introduction.

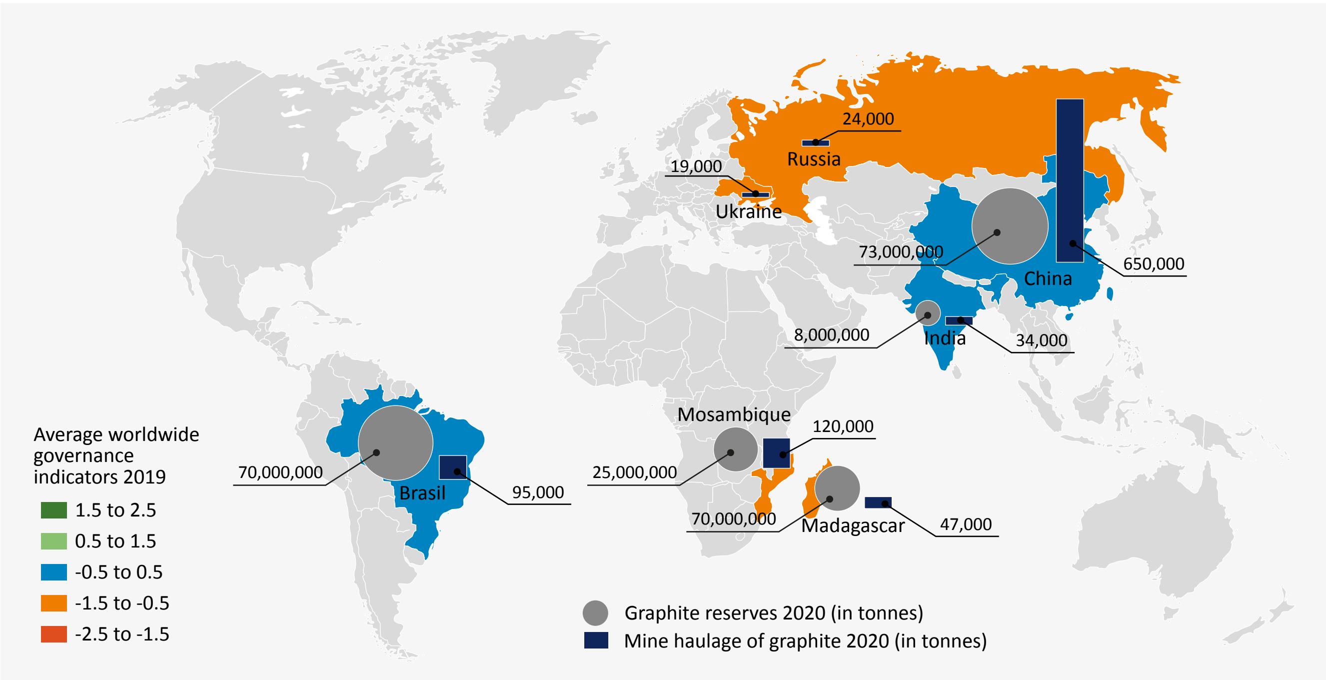

Figure 16: Graphite production and reserves by country (2020). Shown in colour is the World Bank's World Governance Index (average) (2019). Own representation according to Damm & Zhou, 2020; USGS, 2021c and Worldbank, 2021.

235 Damm & Zhou, 2020

236 RAM, 2020

It can therefore be assumed that graphite will remain the dominant anode material for some time to come.

How long do the known resources last?
In 2018, global mine production of natural graphite was about 1.64 million tonnes. This compares to about 300 million tonnes of known graphite reserves. This corresponds to 182 times the production volume in 2018. In addition, graphite can be produced synthetically. Recycling of graphite from lithium-ion batteries does not yet take place for economical reasons.

Is the supply of the EU guaranteed?
Europe currently accounts for only about 2% of global mine production for graphite, resulting in a very high dependence on imports. About 175,000 t of natural graphite were imported into the EU in 2018. This represents 30% of the global imports. Due to the supply risk, the EU has classified natural graphite as a critical raw material. Figure 16 shows the seven largest graphite mine producers and the countries with the largest graphite reserves. These seven countries represent about 90% of the world's graphite mine production. To visualise the country risk, colouring is based on the average of the six World Governance Indicators[237] of the World Bank.

Is raw material extraction sustainable and compliant with human rights?
The raw material extraction of graphite as well as its further processing is associated with high energy consumption and environmental pollution and takes place mainly in countries with low environmental standards. [238]

237 Indicators: Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law und Control of Corruption.

238 Dolega et al., 2020

TABLE OF FIGURES

LIST OF ABBREVIATIONS

3TG	Tin, Tungsten, Tantal, and Gold
ACC	Automotive Cells Company
BAFA	Bundesamt für Ausfuhrkontrolle (Federal Office for Economic Affairs and Export Control)
BEV	Battery-electric vehicle
BESS	Battery energy storage system
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy
BMS	Battery management system
CASE	Connected, Autonomous, Shared, Electric
CIRAF	Cobalt Industry Responsible Assessment Framework
CMRT	Conflict Mineral Report Template
CO_2-eq	Carbon dioxide equivalent – often an effective summary of greenhouse gases
CPT	Climate Protection Targets
DoD	Depth of Discharge
EBA	European Battery Alliance
EEG	Erneuerbare Energien Gesetz (Renewable Energies Act)
EIT	European Institute of Innovation and Technology
ERMA	European Raw Material Alliance
ETIP	European Technology and Innovation Platform
EU	European Union
EuBatIn	European Battery Innovation
EU ETS	European Union Emissions Trading System
ESS	Energy Storage System
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GBA	Global Battery Alliance
GHG	Greenhouse gas – often stated as impact equivalents of carbon dioxide (CO_2-eq).
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
GRI	Global Reporting Initiative
ICEV	Internal Combustion Engine Vehicle
ILC	International Lithium Corporation
IPCEI	Important Projects of Common European Interest

IRMA	Initiative for Responsible Mining Assurance
JV	Joint Venture
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
$LiCoO_2$	Lithium cobalt oxide
nEHS	Nationales Emissionshandelssystem (national emissions trading system)
NMC	Nickel Manganese Cobalt
NPM	Nationale Plattform Zukunft der Mobilität (National Platform Future of Mobility)
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
R&D	Research and Development
RE	Renewable Energies
RMI	Responsible Minerals Initiative
SBT	Science Based Targets
SDGs	Sustainable Development Goals
SoH	State of Health
TCO	Total Cost of Ownership
t-w	Tank-to-wheel
TWh	Terrawatt hour
UN	United Nations
UNEP	United Nations Environment Programme
VDA	Verband der Deutschen Automobilindustrie (Association of the German Automotive Industry)
WEF	World Economic Forum
w-t	Well-to-tank – meaning: "from the borehole to the tank", is a way of looking at the effort required to provide the propulsion energy for motor vehicles from the primary energy extraction to the provision for the vehicle.
w-t-w	Well-to-wheel – literally: "from the borehole to the wheel" is a method of looking at or analysing the energy demand from primary energy production to the traction of the vehicle.

GLOSSARY

Accumulator: Rechargeable electrochemical energy storage device.

Batteries: In the context of this study, the term batteries is used to refer to both primary (non-rechargeable) and secondary (rechargeable) electrochemical energy storage devices.

Cell production / manufacturing: Short for battery cell production / manufacturing.

Circular business models: Business models that help to not only consume natural resources, but to make them further usable by recycling them.

Climate neutrality: No influence of processes or activities on the climate.

Decarbonisation: Reduction of CO_2 and other greenhouse gas emissions.

Draft Batteries Regulation: European Commission's draft for the modernisation of EU legislation on batteries.

Electricity mix: The electricity mix is composed of electricity generated from different electricity sources (coal-fired power, nuclear power, renewable energies, ...).

Emissions budget: The emissions budget refers to the amount of greenhouse gases that may still be released in order to avoid with a certain probability global warming above a certain temperature level.

Gigafactories: Production sites that produce battery cells on a gigawatt-hour scale annually.

Glider: In life cycle assessment, a common description for the remaining vehicle without a drive train.

Greenhouse gas: Gases that contribute to global warming by accumulating in the atmosphere.

Greenhouse gas-neutral: No more greenhouse gases are emitted than can be compensated. Consequently, the greenhouse gas concentration in the atmosphere remains constant.

Gross electricity demand: Gross electricity demand includes the final energy demand for electricity, as well as the associated conversion and transmission losses.

Hydrometallurgical recycling processes: Recycling process in which components are recovered via wet chemical processes. In contrast to pyrometallurgy, these recycling steps can be carried out at comparatively low temperatures.

Industrial batteries: Batteries designed for industrial applications.

Life cycle analysis: Analysis of the impact of products on the environment throughout the product life cycle.

Modal split: Distribution of the traffic volume among different modes or means of transport.

Non-profit organisation: An organisation that does not pursue economic profit objectives.

Plug-in hybrid: Vehicle that has both an internal combustion engine and an electric motor. The battery for operating the electric motor can additionally be charged via an external connection.

Portable batteries: Batteries or accumulators used in (portable) electronic devices.

Power-to-gas: Process in which gases are extracted from water through the use of electricity.

Recyclate: Recycled material recovered from a used product that can be used for a new product.

Reserves: In the context of raw materials, refers to deposits of raw materials that have been reliably proven and are economically recoverable with known technology according to the current status.

Resources: In the context of raw materials, refers to deposits that cannot yet be extracted economically because they have not yet been sufficiently explored or because a suitable extraction technology is lacking. Resources are usually significantly larger in quantity than reserves.

Second life batteries: Batteries that have already been used in a first application and are subsequently used in a second application (possibly after appropriate reconditioning).

Shared mobility: Shared mobility is a concept in which means of transport, such as bicycles or cars, are used jointly.

Spill-over: The effect of outcomes or states on other outcomes or states is called the spill-over effect.

State of health: The "state of health" of batteries indicates how much capacity / energy is usable compared to the initial state. As a rule, the usable capacity / energy decreases in the course of the life cycle of a battery.

Stationary storage: Energy storage systems for stationary applications, used for example for the intermediate storage of renewable energies.

Traction battery: Batteries specifically designed to power hybrid and electric vehicles for road use.

Used batteries / accumulator: Batteries or accumulator at the end of the life cycle.