I / 2022 ▪ Study

Measuring sustainability: A consistent metric for sustainable batteries

Which indicators are relevant and what role does end-of-life management play in China?

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

in cooperation with

VDI|VDE|IT

TÜVRheinland® Precisely Right.

TU berlin

Accompanying Research
BATTERY CELL PRODUCTION

Publisher
VDI/VDE Innovation + Technik GmbH
Steinplatz 1
10623 Berlin

Authors
Vera Beermann
Aiko Bünting
Frederik Vorholt
Frauke Bierau-Delpont
Mischa Bechberger
Roman Korzynietz
Arno Spreen

Editors
Mira Maschke
Isabel Martin
Stefan Wolf

Layout
VDI/VDE-IT, Anne-Sophie Piehl

Berlin, January 2022

Image Credits
Cover page: flyalone/AdobeStock
p. 2: malp/AdobeStock
p. 4; p. 8–14; p. 16–18; p. 19–23; p. 25–27:
AdobeStock/davooda, presentationload

in cooperation with

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Proof of compliance with sustainability requirements in battery production and recycling using indicators is required by legislatures on the one hand and also needed by commercial enterprises on the other hand. Creating a competitive, sustainable and circular battery value chain in Europe requires ensuring fair competition and a competitive environment which is no longer focussed solely on cost, but also on sustainability and circularity. This requires establishing a regulatory framework and enabling corresponding authorities to verify compliance with sustainability requirements. Initiated by regulators, but also by customers and investors who are increasingly demanding verifiable sustainability, the pressure on companies to act has recently grown significantly. Companies are increasingly obligated to design or manufacture their production and products sustainably. Verification of sustainable production and sustainable products as well as the creation of effective framework conditions requires appropiate indicators.

A uniform sustainability metric is therefore required to characterise and compare the sustainability of batteries and their production. Indicators have already been developed for many sustainability aspects, but these indicators are neither equally relevant to the battery industry nor have they all been proven in practice. For the main topics ***Environmental Impacts***, ***Circular Economy & End-of-Life-Management***, ***Social Considerations & Human Rights*** as well as ***Working Conditions***, there are in principle suitable indicators for the measurability of sustainability. Some of these indicators are not specific to a particular sector and are widely used. Others, on the other hand, have a strong focus on industry and have not yet been operationalised in the battery industry in individual cases.

A comparative look at the Chinese recycling industry shows that a large number of measures have been adopted to regulate the circular economy and end-of-life management. Some of the indicators used there, such as material recovery rates, are similarly ambitious to those currently being discussed and introduced promptly at the European level. However, a large part of the measures in China are not binding, so consequently they are not fully implemented by the entire recycling industry. Nevertheless, some of the leading companies are presumably well equipped to also meet the requirements of the upcoming European Battery Regulation for the circular economy. As the tightening of European sustainability requirements goes far beyond the circular economy aspect, however, it remains to be seen whether Chinese battery cells will be able to maintain competitive pressure on the EU domestic market.

1 MEASURABILITY OF SUSTAINABILITY IN BATTERY CELL PRODUCTION

A standard sustainability metric is necessary for sustainable batteries

Batteries are a critical key technology for the transformation of the mobility and energy sectors necessitated by climate concerns. They can make the biggest contribution to the transition to a sustainable, namely climate-friendly, resource-efficient and competitive economy when batteries are manufactured with the lowest environmental impact, using materials sourced and produced with full regard for human rights as well as social and ecological standards. In order for these sustainability requirements for production and products not only to be formulated, but also defined by regulations and verified by the authorities, the **sustainability aspects must be measurable**. This requirement necessitates a corresponding metric which ensures the transparent and interoperable determination of sustainability using indicators.

Battery technology is a key enabler not only for climate-friendly mobility but also for maintaining grid stability as the share of renewable energy production continues to increase. The global demand for battery cells has grown accordingly in the past few years and is forecast to increase by more than a factor of ten by the end of the decade.[1] This is associated with **strong growth in the demand for battery cell production facilities**. The first new production facilities are starting to operate in Europe, with the majority of planned new factories currently in the construction or planning stage. In addition to the challenges of establishing a new industrial sector, the development of a battery ecosystem currently in progress also offers the opportunity to implement criteria which **ensure sustainability of both production and product along the entire value chain** and thus maximize the contribution of batteries to a modern economy. The purpose of corresponding indicators is to enable these criteria to be quantified and thus implement them in regulations.

Regulatory requirements for sustainability are tightened

At the European level, **sustainability is considered as an absolute necessity but also as a competitive advantage**. This is because batteries themselves are neither a universal solution for the climate-specific challenges of the mobility or energy sector transformation, nor do they per se have a positive ecological balance sheet. Nonetheless, sustainably produced battery technology has great potential to become a key technology for low-emission mobility and energy storage. With regard to resource-efficient and competitive battery cell manufacturing, correspondingly high sustainability requirements are placed on batteries which will be sold

1 Beermann, Vorholt, 2022

in the EU (European Union) in the future. One of the core demands is that batteries have to be sustainable, efficient and safe throughout their entire life cycle. Batteries (cells) which meet these requirements can be sold on the domestic European market on the one hand, and on the other hand contribute to achieving the goal of climate neutrality by 2050 established in the **European Green Deal**.[2]

The **draft of the new European Battery Regulation** is instrumental for the creation of a competitive, sustainable and circular battery value chain in Europe. In addition to the transparent reporting of greenhouse gas (GHG) emissions in the manufacturing process this new regulation will also establish minimum requirements for the durability and efficiency of batteries as well as a minimum content of recycled raw materials. The World Forum for Harmonization of Vehicle Regulations of the United Nations Economic Commission for Europe (UNECE) is currently working on a regulation in the form of a **Global Technical Regulation** (GTR) of the United Nations. It calls for obligating vehicle manufacturers to provide proof of a minimum service life for the installed traction batteries.[3] Through these requirements for batteries over their entire life cycle, the upcoming European Battery Regulation and the upcoming UNECE regulation, both of which are expected to be passed in the course of this year, contribute to creating fair competition conditions. In addition, they provide incentives for **more sustainable competition**, which is no longer dominated solely by cost but is oriented towards sustainability and recyclability.

In the interest of a sustainable value chain, "supply chain laws" also obligate companies to address the **origin of purchased products and services** and to ensure regard for human rights as well as social and ecological standards. Several European states, including the Netherlands, France and Great Britain, have already initiated or already implemented corresponding laws at the national level.[4] In Germany the national "Supply Chain Due Diligence Act" was published in the German Federal Law Gazette in July 2021.[5] At the European level, the European Parliament passed the "Report on corporate due diligence and accountability" in March 2021 and thus recommended that the European Commission implement a European supply chain act. On 1 January 2021 the ordinance on the specification of the new due diligence requirements in the supply chain of certain "conflict minerals" also came into force. It aims to ensure transparency and certainty with regard to the sourcing of so-called raw material traders as well as foundries and refineries which source certain raw materials from conflict and high-risk areas.[6]

The tightened regulatory sustainability requirements support the overall goal of establishing a **circular economy for battery raw materials and components** in Europe under compliance with due diligence requirements as well as social and ecological standards.

Customers and investors also impose sustainability requirements

Sustainability has become a strategic necessity. For battery manufacturers as well as companies along the value chain, sustainability should no longer be just a regulatory requirement, but should rather become a key component of the business strategy. Especially because sustainability requirements with regard to climate protection, compliance with human rights and responsible use of raw materials are continually being advanced not only at the political level, but also by customers, investors and interest groups.

The market for Eco, Fair Trade or recycled products has been growing for years. Sales of biotextiles (private households) alone have increased more than forty-fold between 2013 and 2018.[7] Corresponding studies show that ignoring this "trend" is now a business risk.[8] Customers who are increasingly requesting sustainably produced goods and services and thus demand **reliable information on sustainability** have a

2 Europäische Kommission, 2019

3 UNECE

4 Oxfam

5 Bundestag, 2021

6 Europäische Union, 2017

7 Umweltbundesamt, 2020

8 Deloitte

corresponding interest in the measurability and traceability of products and value chains. In a corresponding survey, 79% of respondents indicated that they had already changed their buying preferences on the basis of social, economic and ecological impacts or had at least considered doing so.[9] But investors are also increasingly aware of this aspect. Larry Fink, CEO of the world's largest private investment fund BlackRock, is very direct in the annual letter to the management boards of the world's largest companies 2020 (see Infobox): "Climate risk is investment risk".[10] In the Global Investor Survey by PwC, 79% of the surveyed investors indicated that ecological and social sustainability risks are key considerations for their investment decisions. 49% of investors are even willing to pull capital from companies which do not meet sustainability requirements.[11]

Companies are therefore under growing pressure to act, not only from legislators but also from customers and

> "Given the groundwork we have already laid engaging on disclosure, and the growing investment risks surrounding sustainability, we will be increasingly disposed to vote against management and board directors when companies are not making sufficient progress on sustainability-related disclosures and the business practices and plans underlying them."
>
> Larry Fink, CEO Blackrock

investors who are increasingly demanding transparency with regard to sustainability.

Indicators for many sustainability aspects exist already
The definitions of various sustainability aspects as well as the formulation of specific indicators exist already. The global goals

Figure 1: Overview of the Sustainable Development Goals (SDGs) for socially, economically and ecologically sustainable development. (BMZ,a)

9 Kees et al., 2020

10 Fink

11 Chalmers et al, 2021

for sustainable development shown in Figure 1 (Sustainable Development Goals, SDGs) serve as fundamental principles. In 2015 the international community adopted the Agenda 2030 with the core vision of establishing a world free from fear, want and indignity.[12] The 17 SDGs of the Agenda 2030 encompass economic, ecological and social development aspects and are directed at: countries, civil society, economy, science and every individual. In Germany the status of sustainable development in terms of implementing and/or reaching the Sustainable Development Goals is determined by the German Federal Statistical Office, which utilizes a set of 231 indicators on social, economic and ecological aspects of sustainability.

Due to the many potential indicators, the sources for the identification of indicators relevant to the battery industry for this study were limited to the draft of the new European Battery Regulation, the Product Social Impact Life Cycle Assessment Database (PSILCA) as well as guidelines of the European Commission for reporting on non-financial matters. The indicators which were considered are summarized in table form (Table 1) and described in briefs. The briefs include a short description which contains information on the conventional unit of the indicators and, if applicable, establishes a link to the SDGs. Examples of use in practical applications, if available, are also listed, through which the status of operationalization of the individual indicators is described.

12 BMZ, a

2 SUSTAINABILITY INDICATORS FOR THE BATTERY INDUSTRY

Not all sustainability indicators are equally relevant to the battery industry

There are numerous sustainability indicators, such as the Sustainable Development Goals. With 17 goals and 169 targets, the Agenda 2030 is very comprehensive. Not all of the defined development goals and/or indicators are related to a sustainable and recycling-based battery value chain.[13]

The "Sustainability of battery cell production in Europe" study, published in June 2021 provides an overview of the status quo and the perspectives of the aspects of climate protection, industrial policy, circular economy, raw materials governance, economic feasibility and employment of sustainable battery cell production in Europe.[14]

The present study provides an overview of the sustainability indicators, which pertain to the aforementioned sustainability aspects and are also relevant for battery cell production. In addition to the relevant indicators for determining the implementation of the SDGs or the degree to which the SDG targets have been reached, indicators relevant specifically for battery cell production are considered as well. Battery-related indicators are listed in the draft of the EU Battery Regulation. Important contributions to completion of this framework of sustainability indicators are being developed by international stakeholders such as ETIP Batteries or the Global Battery Alliance (GBA). This chapter provides an overview of the indicators which are relevant for the battery value chain and provides additional information on these indicators.

2.1 Overview of the sustainability indicators

The relevant indicators for the battery industry are listed in Table 1 under the main topics *Environmental Impacts*, *Circular Economy & End-of-Life-Management, Social Considerations & Human Rights* as well as *Working Conditions*. The icons in Figure 2 represent the value-added steps of the battery industry. These icons also indicate which value-added steps the respective indicators primarily apply to.

2.2 Sustainability indicator briefs

The sustainability indicators shown Table 1 and grouped by main topics are described below in individual briefs. These describe the parameters which define the respective indicator and the unit in which the indicator is typically given. Additional information is also provided and the Sustainable Development Goals which are used for the implementation and/or achievement rate of the respective indicators are specified. Examplary use cases give information on whether and how intensively the indicator can be / has been operationalized.

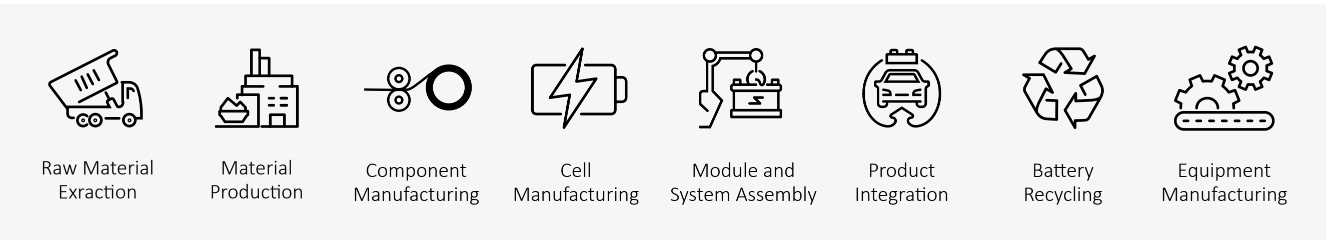

Figure 2: Value-added steps of battery cell production and corresponding icons.

13 BMZ, a

14 Bechberger et al., 2021

Indicator	Value-added step(s) 1	2	3	4	5	6	7	8
Environmental Impacts								
Energy efficiency	●	●	●	●	●	●	●	●
Energy from renewable sources	●	●	●	●	●	●	●	●
Greenhouse gas emissions	●	●	●	●	●	●	●	●
Mining/consumption of natural resources	●	○	○	○	○	○	○	○
Water consumption	●	●	●	○	○	○	●	○
Use of hazardous substances	●	●	●	●	○	○	●	○
Circular Economy & End-of-Life-Management								
Recycling efficiencies	○	○	○	○	○	○	●	○
Utilization rate of secondary raw materials	○	●	●	○	○	○	○	○
Recycling target for batteries	○	○	○	●	●	●	○	○
Battery State of Health (SoH)	○	○	○	○	●	●	○	○
Social Considerations & Human Rights								
Child labour	●	●	●	●	●	●	●	●
Forced labour	●	●	●	●	●	●	●	●
(Occupational) Health and Safety	●	●	●	●	●	●	●	●
Discrimination	●	●	●	●	●	●	●	●
Employment	●	●	●	●	●	●	●	●
Working Conditions								
Working hours, training, fair wages, worker rights, social benefits	●	●	●	●	●	●	●	●

Table 1: Overview of the sustainability indicators by main topic (colour coded) and the steps of the battery cell production value-added steps which are primarily affected.

Environmental Impacts

2.2.1 Environmental impacts

Sustainable battery cell production requires direct and indirect environmental impacts along the entire value chain to be minimized. The use of raw material deposits and use of water as a resource, both directly and indirectly in raw material extraction and production processes, are highly relevant in this regard. In addition to the emission of gases which are harmful to the climate, aspects such as energy efficiency and energy sources in numerous value creation process steps have a decisively effect on the respective environmental impact.[15]

The indicators listed under the main topic of environmental impacts make a significant contribution to determining the implementation and/or achievement rate of various SDGs, which are shown in Figure 3. The environmental impact indicators are distinguished by comparatively good measurability. Clear quantifiable and verifiable targets can be developed and/or tracked using corresponding limits or specified minimum requirements.

Energy efficiency

Typical unit(s): Efficiency [%]

Brief

In general, the **energy efficiency** describes the (energy) expenditure required to achieve the specified benefit. The (technical) energy efficiency is typically specified as efficiency (η) dimensionless or in percent. This is calculated as the ratio of the usable power or energy relative the expended power or energy.[16]

The energy efficiency indicator contributes to the targets of SDG 7 (Affordable and Clean Energy) and SDG 9 (Industry, Innovation and Infrastructure). With regard to energy efficiency, SDG 7 requires that measures are taken to double the worldwide energy efficiency.[17,18] SDG 9 is targeted at

	3 GOOD HEALTH AND WELL-BEING	6 CLEAN WATER AND SANITATION	7 AFFORDABLE AND CLEAN ENERGY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	11 SUSTAINABLE CITIES AND COMMUNITIES	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	13 CLIMATE ACTION	15 LIFE ON LAND
Energy efficiency			✓	✓				
Energy from renewable sources			✓	✓	✓		✓	
Greenhouse gas emissions			✓	✓	✓		✓	
Mining/consumption of natural resources						✓		
Water consumption		✓				✓		✓
Use of hazardous substances	✓					✓		

Figure 3: Applicability of the environmental impact indicators to the SDGs.

15 Bechberger et al., 2021

16 Europäische Union, 2012a

17 König, 2021

18 BMZ, b

technological progress and innovation, which in turn is the foundation for improved energy efficiency.[19]

Operationalization
The **energy efficiency** indicator is already used in the form of energy efficiency categories/labels, for example in the area of electric appliances (e.g. refrigerators, washing machines).[20,21]

The **EU Energy Efficiency Targets** call for increasing overall energy efficiency by at least 32.5% in comparison to projections of the expected energy consumption by 2030.[22,23]

The draft of the **EU Battery Regulation** requires that battery cell production, among other things, should have a higher level of energy efficiency. A battery-specific indication of energy efficiency (i.e. the amount of energy expended to produce one unit of battery storage capacity, $kWh_{storage}/kWh_{expenditure}$) should be provided in future via the digital battery passport, which also provides information on the CO_2 footprint over the entire life cycle.

For vehicles with alternate drivetrains, energy efficiency also plays a role in evaluating the drivetrain efficiency, i.e. how much of the supplied energy is actually converted to kinetic energy. To produce 1 kWh of mechanical kinetic energy, battery electric vehicles (BEVs) require 1.4 kWh, fuel cell electric vehicles (FCEVs) require 2.8 kWh and combustion engines powered by synthetic fuels require 8.7 kWh of renewable energy.[24] Accordingly, a BEV is significantly more energy efficient than other alternative drive technologies.

Energy from renewable sources

Typical unit(s): Percentage of renewable energy [%]

Brief
The indicator **energy from renewable and non-renewable sources** describes the share of energy which is required for a process under consideration, e.g. for manufacturing a product, and which comes from renewable sources. The share of renewable energy is specified in percent and is calculated as the renewable energy consumption divided by the total energy consumption. This indicator can be applied along the entire value chain and is highly relevant, since energy production from fossil sources causes a considerable part of the greenhouse gas (GHG) emissions in production processes.[25] The energy consumption in every (process) step should be as small as possible (see Energy efficiency indicator) and should as far as possible be covered by energy from renewable sources, such as wind and solar energy. The larger the share of renewable energy, the more sustainable production is with regard to GHG emissions.

The indicator energy from renewable and non-renewable sources contributes to SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).[26] In this context, SDG 11 addresses the goal of minimizing the environmental impact caused by cities with a focus on air quality.

19 UNRIC, a

20 Umweltbundesamt, 2021

21 Europäische Union, 2019

22 Europäische Kommission, 2021

23 Europäische Union, 2012a

24 Bechberger et al., 2021

25 Bechberger et al., 2021

26 Bayerischer Industrie- und Handelskammertag e.V., 2020

Operationalization

There are currently numerous **new production facilities** being built for manufacturing batteries. Currently, a battery cell factory consumes around 40 to 50 GWh of energy per GWh of produced battery cell storage capacity.[27] As the use of renewable energy is a significant factor for sustainability, the availability of a renewable energy supply should already be considered during site selection. Accordingly, the production of renewable energy on site should be evaluated during the planning and construction of production facilities. For example, the roofs of large production halls can be equipped with photovoltaic systems, or corresponding supply contracts can be concluded. For example, seven German states have already decided on mandatory installation of photovoltaic systems on roofs in order to accelerate the use of renewable energy and reduce GHG emissions. This requirement primarily applies to companies which build new non-residential buildings and larger parking lots. The requirement also applies to some residential buildings or the renovation of roofs on existing buildings.[28] The coalition agreement "MEHR FORTSCHRITT WAGEN" (venture more progress) between the Sozialdemokratische Partei Deutschlands (SPD), BÜNDNIS 90/DIE GRÜNEN and the Freie Demokraten (FDP) from November 2021 specifies that the use of rooftops for solar energy production should be mandatory for new construction of commercial buildings.[29]

Greenhouse gas emissions

Typical unit(s):
Amount of GHG [g/kWh or $g/kg_{\text{Raw material}}$]

Brief

The indicator **Greenhouse gas emissions** (GHG) encompasses all GHG emissions generated in the processes and production steps of a company. Both direct emissions which are produced on site, and indirect emissions resulting from upstream processes or purchased raw materials, components or energy, must be included. The amount of GHG can be specified in g or kg per kWh of produced battery capacity or per kg of produced raw material.

This indicator is linked closely with the indicators "Energy Efficiency" and "Energy from renewable sources " and is also often called the **"CO_2 footprint"**.

The indicator Greenhouse gas emissions as well as the indicator "energy from renewable and non-renewable sources" both contribute to SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).[30],[31]

Operationalization

In battery cell production, most GHG emissions result from the **energy supply** for various process steps in the value chain as well as the total energy demand of the production. Besides the energy efficiency, the emissions balance is primarily determined by the production location and the locally and/or regionally available energy supply.[32] The process emissions, for example those generated during **mining**, also contribute the the GHG footprint. These can often be reduced by extracting raw materials from other sources, by using other processes or through substitution of raw materials. Another option for reducing emissions is to **bind or capture process gases** to prevent them from entering the environment.[33,34,35]

27 Jinasena et al., 2021

28 Kühl, Petruschke

29 SPD, BÜNDNIS 90 / DIE GRÜNEN, FDP, 2021

30 Bayerischer Industrie- und Handelskammertag e.V., 2020

31 BMZ, c

32 Bechberger et al., 2021

33 Wittpahl, 2020

34 IEA

35 Kretschmer

The **electrification** of process steps or switching to sustainable energy sources such as green hydrogen can help reduce the carbon footprint of many production processes as well.[36] However, the electrification of processes should be based on renewable energy supplies right from the beginning. Electrification of industrial processes is already being implemented through the use of heat pumps and electrode boilers to generate hot water and steam, or by using electric arc furnaces in metal manufacturing.

With respect to battery cell production, the indicator is applied in the **draft of the new European Battery Regulation**, which initially provides for an information obligation and then an increase in the carbon footprint requirements in the form of a limit value. Due to the high significance of GHG emissions for the sustainability of battery cell production, this indicator is one of the first key performance indicators (KPIs) to be implemented within the framework of the **Battery Passport of the Global Battery Alliance** (GBA).[37,38]

The indicator is also used among other things in drafting targets for limiting GHG emissions in the EU and Germany, for example for defining specific CO_2 reduction targets in the traffic sector and the CO_2 pricing of energy sources in the mobility sector which came into force at the beginning of 2021.

Mining/consumption of natural resources

Typical unit(s): Proportion [%]; Weight [kg]

Brief

The indicator **mining and/or consumption of natural resources** describes the amount of a mined natural raw material contained in a product placed on the market, such as a battery. This amount is specified either as a relative amount in percent or as an absolute weight, usually in kg.

Declaring the amount of natural resources extracted for the products and business activities of a company is of critical importance. Companies can represent the environmental impacts of their economic activities in a so-called ecological balance sheet (input-output statement). With regard to the sustainable development targets, the indicator contributes to SDG 12 (Responsible Consumption and Production).

Operationalization

The EU defines clear standards for companies to maintain **due diligence in supply chains** for the purpose of reducing environmental risks associated with raw materials for battery cell production. Concrete obligations and systems for economic operators who place batteries with a capacity above 2 kWh on the market, requiring them to establish supply chain due diligence policies, are primarily addressed in articles 39 and 72 of the EU Regulation 2019/1020.[39] The **United Nations** have also published guidelines and recommended actions for sustainable raw material extraction, which among other things establish that human rights, occupational health and safety and conflict risks in mining, including continuous transparency and anti-corruption measures, are essential in addition to environmental management.[40]

Water consumption

Typical unit(s):
Water consumption [m^3]
Water footprint [m^3/a]

Brief

The **water consumption**, also called the water footprint, is an indicator of the consumption of water resources. This indicator can be used to provide information on the direct and indirect water consumption related to a process, a product, a company, a sector, a country or a private individual. It includes both the direct **consumption of water**

36 Wittpahl, 2020

37 GBA, 2020

38 World Economic Forum, 2019

39 Europäische Union, 2020

40 United Nations, 2019

and the contamination of water over the entire cycle – in most cases from the supply chain to the end user(s). The water consumption indicator contributes to SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production) and SDG 15 (Life On Land).[41,42,43] SDG 6 primarily addresses the targets of efficient use of water resources and sanitation. For SDG 12, the indicator primarily targets the sustainable and efficient use of raw materials and SDG 15 focusses on protecting ecosystems and combating desertification.

Operationalization
To classify the water footprint, the consumed water is organized into categories: Green (naturally occurring soil water and rainwater), Blue (groundwater or surface water), Grey (water contaminated by the manufacturing process).

The water footprint was developed by Arjen Hoekstra at the United Nations Educational, Scientific and Cultural Organization Institute for Water Education (UNESCO-IHE) as a way of measuring the amount of water which is consumed and/or contaminated along the entire supply chain for the production of goods and services. Hoekstra also founded the **Water Footprint Network** (WFN) as a non-profit multi-stakeholder network. The goal of the WFN is to create a network for exchange, to raise awareness of water as a resource, to build corresponding capacities, to disseminate knowledge and data and to exert corresponding influence on policy and practice. Activities and approaches to optimizing the use of water resources are also initiated jointly with partners.

The draft of the **EU Battery Regulation** mandates that binding strategies to capture the environmental risks and impacts must be incorporated into the supply chains. Water consumption in particular is mentioned. The water consumption indicator serves to capture the environmental risks in this regard.

An established indicator is the water consumption in the **textile industry**, which has been applied in practice for years and enters into certificates such as the “Blue Angel”.[44]

Use of hazardous substances

Typical unit(s):
Amount [litres or kg per end product]

Brief
Tracking the **use of hazardous substances** is relevant for many process steps, since e.g. cleaning or extraction steps frequently involve the use of chemicals and additives, many of which are **harmful to health or the environment**. The use of hazardous substances is specified as amount in litres or kilogram per end product. However, hazardous substances are often produced as by-products in processes in addition to the direct use of such substances. Therefore the use of **process chemicals** and other hazardous substances should also be reviewed in detail with respect to more sustainable alternatives or process control changes. Processes should also be well understood and controlled, in order to minimize risks due to produced **by-products** and to be able to initiate suitable corrective action.

The indicator contributes to SDG 3 (Good Health and Well-Being) and SDG 12 (Responsible Consumption and Production). In order to achieve SDG 3, the indicator in particular addresses the target of reducing the number of deaths due to hazardous chemicals and contamination and pollution of the air, water and ground.[45] SDG 12 requires more environmentally friendly use of chemicals.

41 BMZ, d

42 BMZ, e

43 BMZ, f

44 Bundesregierung, 2020

45 BMZ, g

Operationalization

Using the indicator **use of hazardous substances** allows companies to declare how successful the measures implemented to **avoid hazardous substances**, worrying substances or biocides are with regard to their occurrence in products, business processes and the supply chain. In this context existing standards for labelling chemicals, such as **REACH, CLP classification**, should be made mandatory globally and applied systematically.[46] The REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation and CLP (Classification, Labelling and Packaging of Chemicals) are both applicable to chemicals and in force through EU law. REACH is aimed at evaluation and reduction of risk to humans and the environment posed by chemicals, while CLP regulates the labelling and packaging of chemicals. The burden of proof obligation to comply with these regulations are borne not only by chemical industry companies, but by all companies who work with potentially hazardous materials.[47]

In countries with **environmental regulations** which govern the use of hazardous substances, problems caused by worrisome substance can be mitigated to some degree. But countries with inadequate environmental regulations and small penalties for violating these are repeatedly the source of reports on environmental damage such as acidification of water bodies due to the improper handling of chemicals. This could be remedied through mandatory directives on the use of hazardous substances and in particular also of corresponding process by-products, as well as more consistent environmental regulations.[48]

46 Europäische Union, 2012b

47 REACH

48 Dolega et al, 2020

Circular Economy & End-of-Life-Management

2.2.2 Circular Economy & End-of-Life-Management

In order to close material cycles and avoid the improper disposal of batteries, requirements applying throughout the EU and framework conditions for a circular economy and the end-of-life management of batteries must be harmonized and established. Reliable information on the health status of batteries in this context is particularly relevant for 2nd-use applications. For waste batteries which are no longer suitable for alternative applications, it is necessary to specify targets for collection rates, define recycling efficiencies and attain recycling rates for secondary raw materials in the production process. By creating recycling markets for batteries and the secondary raw materials recovered from them, material cycles can be closed and trade barriers as well as distortion of competition can be avoided.[49] All of the relevant indicators are quantifiable and can be tracked and verified consistently through targets and limits.

The indicators listed under the main topic of Circular Economy & End-of-Life-Management make a crucial contribution to determining the degree of implementation or target achievement of various SDGs shown in Figure 4.

	8 DECENT WORK AND ECONOMIC GROWTH	11 SUSTAINABLE CITIES AND COMMUNITIES	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Recycling efficiencies	✓		✓
Utilization rate of secondary raw materials	✓		✓
Recycling target for batteries	✓	✓	✓
Battery State of Health (SoH)	✓		✓

Figure 4: Applicability of the Circular Economy & End-of-Life-Management indicators to the SDGs.

Recycling efficiencies

Typical unit(s): Proportion [%]

Brief

The **recycling efficiency** of a battery recycling process is described as the ratio in percent of the mass of the attributable output fraction and the mass of the input fraction consisting of waste batteries and storage batteries. The input fraction is the mass of the waste batteries and storage batteries supplied to the recycling process and the output fraction is the mass of the materials produced from the input fraction by the recycling process, which without any further treatment are no longer waste or can be used for their original purpose or another purpose.[50] As the indicator already implies, the main value-added step concerned is **battery recycling**. However, the requirements associated with this indicator also contribute indirectly to the value-added steps material production, component manufacturing, cell manufacturing and module / system assembly, since these process steps are already critical for subsequent efficient recycling and the secondary raw materials in turn are the starting point for further production.

The recycling efficiency indicator contributes to SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). The indicator addresses SDG 8 as it promotes the goal of decoupling economic output and prosperity from resource consumption. Efficient recycling contributes to achieving this goal. SDG 12 is addressed by quantifying targets for the sustainable and efficient use of natural resources and the avoidance and/or recycling of waste.[51,52]

49 Europäische Union, 2020

50 Europäische Kommission, 2012

51 BMZ, h

52 BMZ, c

Operationalization

The **German Battery Act**[53] already stipulates concrete recycling efficiencies for specific battery types. As an example, these are 75% for nickel-cadmium batteries, 65% for lead-acid batteries and 50% for all other batteries.[54,55]

For lithium-ion batteries, the draft of the **EU Battery Regulation** calls for an overall recycling efficiency of at least 65% as of 2025 and at least 70% as of 2030. With regard to specific raw materials, as of 2025 the recovery rates for cobalt, nickel and copper should be at least 90% and for lithium at least 35%. By 2030 these material-specific rates should be increased to 95% for cobalt, nickel and copper and to 70% for lithium.[56]

Utilization rate of secondary raw materials

Typical unit(s): Rate [%]

Brief

The **utilization rate for secondary raw materials** describes the proportion of recycled raw materials in produced economic goods in relation to the raw materials initially introduced into the value chain and is indicated in percent. The purpose of the utilization rate for secondary raw materials is to close **value creation loops**, to continue using raw materials after their initial use and thus to enable the efficient and sustainable production of goods. Mandatory utilization rates ensure that corresponding industrial recycling processes are developed and utilized. This also ensures the development of markets for secondary raw materials. Trade barriers and distortion of competition due to the implementation of different rates can be avoided by specifying these through (EU) standardized regulations and laws.[57] Like the recycling efficiency indicator, this indicator contributes to SDG 8 and 12.

Operationalization

The draft of the **EU Battery Regulation** calls for a mandatory specification of the recycled material content in new batteries as of 2027. As of 2030 the minimum recycled material content for cobalt, nickel and lithium in active materials should be prescribed and should be at least 12% for cobalt and at least 4% for nickel and lithium. As of 2035 these targets are expected to be increased, with the content increasing to 20% for cobalt, 12% for nickel and 10% for lithium.[58]

However, it is impossible to predict how the recycled material amounts will develop in relation to the raw material demand in production, since advances are continually being made at the cell chemistry level, for example in order to greatly reduce or completely eliminate the amount of critical raw materials (e.g. increase of the nickel content compared to the cobalt and manganese content of the cathode).

Recycling target for batteries

Typical unit(s): Rate $[\%_{produced\ kWh}]$

Brief

The indicator **collection target / collection quota for batteries** describes the absolute amount or respectively the proportion of batteries to be collected after the (first) use. This is intended to ensure that as many waste batteries as possible remain in the cycle and are not disposed of improperly at the end of their service life. Stipulating collection targets also ensures that sufficient waste batteries are available to be recycled. The collection quota is calculated as the mass

53 Bundestag, 2020

54 Bundestag, 2020

55 Bundestag, 2009

56 Europäische Union, 2020

57 Europäische Union, 2020

58 Europäische Union, 2020

of waste batteries which were returned within a defined period, in proportion to the average mass of batteries which were placed on the market over a defined prior period.[59] Like the recycling efficiency indicator, this indicator contributes to SDG 8, 11 and 12.

Operationalization

Binding and sufficiently high **collection quotas** are also important since collection quotas which are too low are problematic from an economic feasibility aspect. Recycling technologies are capital-intensive and only economically feasible at significant **economies of scale**.[60]

The new **German Battery Act**[61] in force since January 2021 stipulates a collection quota of 50% for device batteries.[62] In comparison, the current **draft of the EU Battery Regulation** calls for significantly stricter collection requirements: The collection quota is expected to be increased to 65% as of 2025 and to 70% as of 2030. In contrast, a collection quota of 100% is stipulated for waste batteries from electric vehicles.

Battery State of Health (SoH)

Typical unit(s): SoH [%]; Residual capacity [Ah]; Operating hours [h]

Brief

The **State of Health** (SoH) is one of the key indicators for describing the **performance** of a battery. It provides information on the condition of the tested battery in comparison to its ideal or initial condition. The SoH is defined by the quotient of the maximum (residual) storage capacity and the initial or optimal storage capacity of the battery. During its service life, the storage capacity of a battery drops due to cell ageing, which is caused by changes in the cell chemistry and/or a shift in the electrochemical equilibrium. Batteries with a significantly reduced residual capacity are, for example, no longer fully suitable for automotive applications since the reduced battery storage capacity leads to a reduced vehicle range.[63,64] Insofar, this indicator is also very important with regard to establishing a market for used electric vehicles and for the second use ("second life") of batteries from automotive applications.

Like the recycling efficiency indicator, the SoH indicator contributes to SDG 8 and 12.

Operationalization

Determining the SoH of a battery requires evaluating various input parameters in a **Battery Management System (BMS)**. Accessing data such as the operating hours or State of Charge (SoC) and collecting dynamic operating data are significant challenges. The first type of data is frequently owned by the automotive manufacturers, so it is necessary to clarify who may use this data, and in what form. Dynamic data can also be determined using artificial intelligence (AI) or alternately measured directly in shops. **Corresponding regulations** have to be created, so that the BMS can be used to obtain reliable information on the SoH with reasonable effort.

In addition to capturing relevant data for determining the SoH, in practice the manner in which the battery is treated also plays a determining role in ensuring its performance and health for as long as possible. **Optimized battery charging** (communication according to ISO 15118), for example, is enormously important for the used vehicle market as well as second-life applications.

59 Bundestag, 2009

60 Europäische Union, 2020

61 Bundestag, 2020

62 Bundestag, 2020

63 BioLogic

64 Neißendorfer

Social Considerations & Human Rights

2.2.3 Social Considerations and Human Rights

The production of lithium-ion batteries is currently still often subject to public criticism that human rights violations occur in the supply chain. This applies in particular to mining of raw materials in countries such as the Democratic Republic of Congo or in South America. However, adequate consideration also has to be given to social concerns when establishing the new industry in Europe. There is a lot of overlap between the main topics **social considerations and human rights**, which is why they are considered together here.

According to the "Universal Declaration of Human Rights", human rights are inalienable rights and basic freedoms which all humans have equally at birth.[65] These include the right to life, liberty and security of person (article 3) or the fact that no one shall be subjected to torture or to cruel, inhuman or degrading treatment or punishment (article 5). Thus compliance with human rights, which can be used as an independent, high-level indicator, encompasses many rights and freedoms which overlap with the indicators described below under the main topic of social considerations. The globalised economy shows in various forms that corporate action - consciously or unconsciously - can lead to the violation of human rights. Although from a formal point of view the punishment of human rights violations does not take place at the level of companies, but at the level of the countries concerned that have ratified a human rights treaty, it is nevertheless the responsibility of corporate action to always and comprehensively ensure compliance with human rights in the economic processes for which the company is responsible. The reporting standards of the Global Reporting Initiative (GRI) call for companies to disclose the measures, strategies and objectives implemented for the company and its supply chain in order to ensure that human rights are respected all over the world and that forced and child labour as well as all forms of exploitation are prevented. These individual aspects of protecting human rights are described below.

The indicators listed under the main topic Social Concerns and Human Rights make a crucial contribution to determining the degree of implementation or target achievement of various SDGs, which are shown in Figure 5.

	1 NO POVERTY	3 GOOD HEALTH AND WELL-BEING	4 QUALITY EDUCATION	5 GENDER EQUALITY	8 DECENT WORK AND ECONOMIC GROWTH	10 REDUCED INEQUALITIES	16 PEACE, JUSTICE AND STRONG INSTITUTIONS
Child labour					✓		✓
Forced labour				✓	✓		
(Occupational) Health and Safety		✓			✓		✓
Discrimination	✓		✓	✓	✓	✓	
Employment					✓		

Figure 5: Applicability of the Social Considerations and Human Rights indicators to the SDGs.

65 UNRIC, b

Child labour

Typical unit(s): Children in child labour or proportion of these children out of all children

Brief

The indicator **child labour** describes work performed by children for which they are too young, which is dangerous or exploitative, which is harmful to physical or mental development or which interferes with children's schooling.[66] It is necessary to distinguish between normal tasks such as helping at home or legal employment of youth and exploitation of children. Most countries have enacted laws which stipulate a minimum age of 14 to 16 years for legal employment. In Germany, the minimum age is 15 years with some exceptions for light-duty activities.

According to the current annual reports by Unicef and the International Labour Organisation (ILO), in 2020 **160 million children** around the world had to perform work which by definition is child labour.[67] In Sub-Saharan Africa the proportion of children who have to perform such work is 24%, in East and South-East Asia 6.2%, and in North America and Europe 2.3%. It is therefore a **global problem** with greatly varying prevalence in different regions. It follows that this indicator is relevant for the entire value chain, with raw material mining and processing being particularly affected due to deposits being limited to certain regions.

This indicator contributes to SDG 8 (Decent Work and Economic Growth) as well as SDG 16 (Peace, Justice and Strong Institutions).

Operationalization

With the Agenda 2030 almost all countries in the world have agreed to ensure that **the worst forms of child labour are prohibited and eliminated**[68] and to eliminate all forms of child labour by 2025.

The International Labour Organisation prepares statistics on child labour, differentiated by age, type of activity and employment sector. The ILO also publishes the collected data regularly in conjunction with Unicef.

Child labour is clearly defined and the three important international human and employment rights standards (Convention on the Rights of the Child, ILO Minimum Age Convention (no. 138) and the universally ratified ILO Worst Forms of Child Labour Convention (no. 182)), **place legal limits on child labour** and form the foundation for national and international measures to end child labour.

Forced labour

Typical unit(s): Prevalence of forced labour in the population; Proportion of goods in a sector which are produced using forced labour

Brief

Forced labour is understood as the general and objectively unlimited utilization of labour against the will of the affected person.[69] The Abolition of Forced Labour Convention of the International Labour Organization, also known as the ILO convention 105, came into force on 17 January 1959 and has been ratified by 176 countries to date (as of August 2021).[70] The ILO estimates that still almost **25 million people** are exploited through forced labour annually.

66 Charbonneau

67 ILO & UNICEF, 2021

68 The United Nations include the following among the „worst forms of child labour" (ILO-convention no. 182 from 1999): Slavery and practices similar to slavery, forced labour including the use of child soldiers, child prostitution and child pornography, criminal activities such as exploiting children as drug couriers as well as other forms of work which can harm the health and safety of children.

69 Beck, 2014.

70 DGVN

This indicator contributes to SDG 5 (Gender Equality) and SDG 8 (Decent Work and Economic Growth).

Operationalization
Even though data on forced labour are published by, for example, the ILO, a simple global accounting isn't possible due to concealment. Therefore the publicly accessible data is generated through verified investigations and interviews, with extensive efforts to close data gaps.[71]

In Germany the Service Centre against Labour Exploitation, Forced Labour and Human Trafficking works throughout Germany to establish sustainable structures for supporting victims and effective prosecution of perpetrators.

The study by the *Global Compact Network Germany: Modern Slavery and Labour Exploitation – Challenges and Solution Approaches for German companies* by the German Global Compact Network examines the **risks of modern slavery** in practice. The risks are considered separately in four key sectors (automotive industry, hotel industry, food sector and textile industry).

(Occupational) Health and Safety

Typical unit(s): Number of cases per month/year/business/100,000 employees

Brief
People fall ill and die every day as a result of workplace accidents or occupational diseases. According to the World Health Organization (WHO)/ILO **360 million non-fatal workplace accidents** happen every year (with over four days of lost time) and almost 2 million people die due to work-related causes.[72] The health and (occupational) safety indicator is not industry-specific and is highly relevant. The indicator is typically specified as incidence rates of fatal and non-fatal workplace accidents. It is determined either as the accident rate, which is the proportion of incidents relative to a specific number of employees and provides information on the degree to which workers in a reference group are exposed to work-related risks, or as the accident frequency, which reflects the proportion of incidents relative to a specific number of working hours. Thus the accident frequency provides information on the likelihood that workers in a reference group suffer workplace accidents relative to the number of hours worked.

The indicator contributes to SDG 3 (Good Health and Well-Being), SDG 8 (Decent Work and Economic Growth) as well as SDG 16 (Peace, Justice and Strong Institutions).

Operationalization
Among other things, the indicator supports **occupational health and safety**. In companies, this indicator is used among other things to determine what measures are necessary in order to prevent workplace accidents from recurring.

The indicator is also used by accident insurance providers who provide compensation for the consequences of accidents at work, on the way to work and due to occupational diseases and use this indicator to, among other things, inform themselves about the current state and developments regarding accidents and occupational diseases.[73]

Discrimination

Typical unit(s): Discrimination cases per month/year/business/100,000 employees

Brief
Millions of women and men around the world are denied access to jobs and education opportunities or are limited to specific occupations and/or receive less compensation on the basis of individual or group-specific attributes. **Discrimination is not industry-specific** and is a gross violation of human rights.

71 ILO, 2012

72 ILO

73 DGUV, 2021

It is determined as the number of discrimination cases in proportion to a specific reference value such as time periods, individual companies or the number of employees.

The indicator contributes to SDG 1 (No Poverty), SDG 4 (Quality Education), SDG 5 (Gender Equality), SDG 8 (Decent Work and Economic Growth) and SDG 10 (Reduced Inequalities).

Operationalization
Among other things, the indicator is used to formulate **business diversity targets** and/or concepts. According to the guidelines on non-financial reporting (methodology for reporting non-financial information) (2017/C 215/01), companies should among other things specify how the objectives of their diversity policy are taken into consideration in succession planning, selection, nomination and evaluation. They should also disclose the role of the competent board committees in those processes.

Anti-discrimination is also established in the draft of the new European Battery Regulation. With regard to social risks, strategies for **meeting due diligence requirements** are stipulated here as well.

At the German national level, the independent Federal Anti-Discrimination Agency is the governing body and as such submits a report on discrimination to the German Bundestag at four-year intervals.

Employment

Typical unit(s): Ratio of employees (%)

Brief
The employment rate is an indicator which specifies the **ratio of employees** to the entire population. The employment rate can be applied specifically to certain groups and thus, for example, reflect the ratio of employees within an age group relative to the whole population of the same age group. In addition, the employment rate can also be specified for certain regions or e.g. the European Union. At the EU Social Summit in May 2021, the participants issued a declaration setting an employment rate target of at least 78% within the EU by the end of the decade.[74]

In the target definition for SDG 8 (Decent Work and Economic Growth) the indicator serves to verify implementation of the goal of making better use of the labour force potential in the future. This goal applies both to the entire working-age population and also specifically to people in the older age group (60–64 years old).

Operationalization
In its guidelines for preparing sustainability reports, the Global Reporting Initiative calls for declaring the **total number and rate of new hires** during the reporting period.

In the sustainability barometer the employment rate indicator serves to establish collective opinion with regard to the energy and mobility transition. Questions include whether these create more jobs in Germany than they eliminate or whether the respondents are afraid of losing their jobs due to the energy and mobility transition.[75]

The widespread use of the employment rate and/or employment relations proves that this indicator is absolutely suitable for practical use. It is currently not applied directly to individual companies.

74 ZEIT ONLINE

75 Wolf et al, 2021

Working Conditions

2.2.4 Working conditions

The topic of working conditions encompasses a wide range of indicators, which are relatively generic and not highly specific. Indicators such as **working hours, education, fair wages, worker's rights** and **social benefits** are relevant for workers far beyond battery cell production, but to some extent very differently on a national, regional and industry-specific basis. For this reason the full scope of the aforementioned indicators is not addressed in this study. Since they are relevant nevertheless, a summary of how they can be defined and measured is provided.

The indicators listed under the main topic of working conditions make a crucial contribution to determining the degree of implementation or target achievement of various SDGs, which are shown in Figure 6.

Working Conditions

Typical unit(s): -

The **working hours** indicator describes the time during which an employee makes their labour available to the employer. It is defined as the time between the start and end of the workday, less breaks.[76] Adherence to working hours can be quantified by regularly and correctly documenting **absolute or percent deviations from allocated times**.

This indicator contributes to SDG 8 (Decent Work and Economic Growth).

	1 NO POVERTY	3 GOOD HEALTH AND WELL-BEING	4 QUALITY EDUCATION	8 DECENT WORK AND ECONOMIC GROWTH	10 REDUCED INEQUALITIES	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Working hours				✓		
Training		✓	✓	✓		
Fair wages	✓	✓		✓	✓	✓
Worker rights				✓	✓	✓
Social benefits	✓	✓				

Figure 6: Applicability of the Working conditions indicators to the SDGs.

76 makeITfair, 2007

The **training** indicator describes whether and how well people are trained or educated for the work they are performing. Two aspects have to be considered: (1) **Basic training due to safety aspects** if qualifications are lacking and (2) Training of **human resources**. Aspect (1) can be quantified if companies disclose how high the **percentage of trained or educated employees** in the company is. Aspect (2) describes the training of human resources. High-quality, needs-based training of employees provides a long-term and sustainable pay off, especially for companies but also for individuals and society. In this case the indicator can be measured as the proportion of training positions relative to the number of employees.

This indicator contributes to SDG 3 (Good Health and Well-Being), SDG 4 (Quality Education) and SDG 8 (Decent Work and Economic Growth).

The **fair wages** indicator signifies whether a worker receives fair compensation for the work or activity they are performing. Wages are typically measured and indicated as yearly earnings in the corresponding currency.

This indicator contributes to SDG 1 (No Poverty), SDG 3 (Good Health and Well-Being), SDG 8 (Decent Work and Economic Growth), SDG 10 (Reduced Inequalities) and SDG 12 (Responsible Consumption and Production).

The **rights of employees** establish fundamental framework conditions in the work environment, such as reliable payment of compensation, the right to equal treatment, right to vacation, etc. This indicator can be quantified as the number of breaches of contract and/or complaints against breaches of contract.

This indicator contributes to SDG 8 (Decent Work and Economic Growth), SDG 10 (Reduced Inequalities) and SDG 12 (Responsible Consumption and Production)

Social benefits encompass all monetary, service and in-kind benefits afforded to the individual or private household. These serve to mitigate and/or offset social risks and needs and are provided by the employer/company, the government or public-sector organizations.[77] Social benefits can become quantifiable by determining if and to what extent these are provided. This indicator contributes to SDG 1 (No Poverty), SDG 3 (Good Health and Well-Being).

77 Lernhelfer

3 CASE STUDY: SUSTAINABILITY OF BATTERY RECYCLING IN CHINA

Over the past decade China has grown into the world's largest market for electric vehicles. Sales of so-called New Energy Vehicles (NEV) have increased from approx. 350,000 vehicles per year in 2015 to over 2 million NEVs just in the first three quarters of 2021. To put these numbers in context, Figure 7 also shows the total registration numbers for battery-electric and plug-in hybrid vehicles in Germany, in addition to the sales figures for China. Hybrid vehicles, which do have a battery but cannot be charged from an external power source, are not included in these statistics since they are not considered as NEVs in China.[78,79,80,81,82]

In China a service life of four to eight years is assumed for the traction battery. At the end of this service life the usable capacity of the battery has dropped to between 70 and 80% of its initial value. The associated reduction in range can lead to battery replacement and corresponding returns of waste batteries from NEVs. While approx. 70,000 tons or 12 GWh of waste batteries where collected in 2019, this was forecast to increase to approx. 200,000 tons or 25 GWh in 2020. For 2025, approx. 980,000 tons or 125 GWh of waste batteries are expected (see Figure 8).[83]

In order to prevent the toxic substances in the waste batteries from entering the environment and to allow valuable raw materials to be recycled, these batteries have to be collected and professionally processed or recycled systematically. The Chinese government has developed numerous regulations, measures, and standards to ensure that this happens.

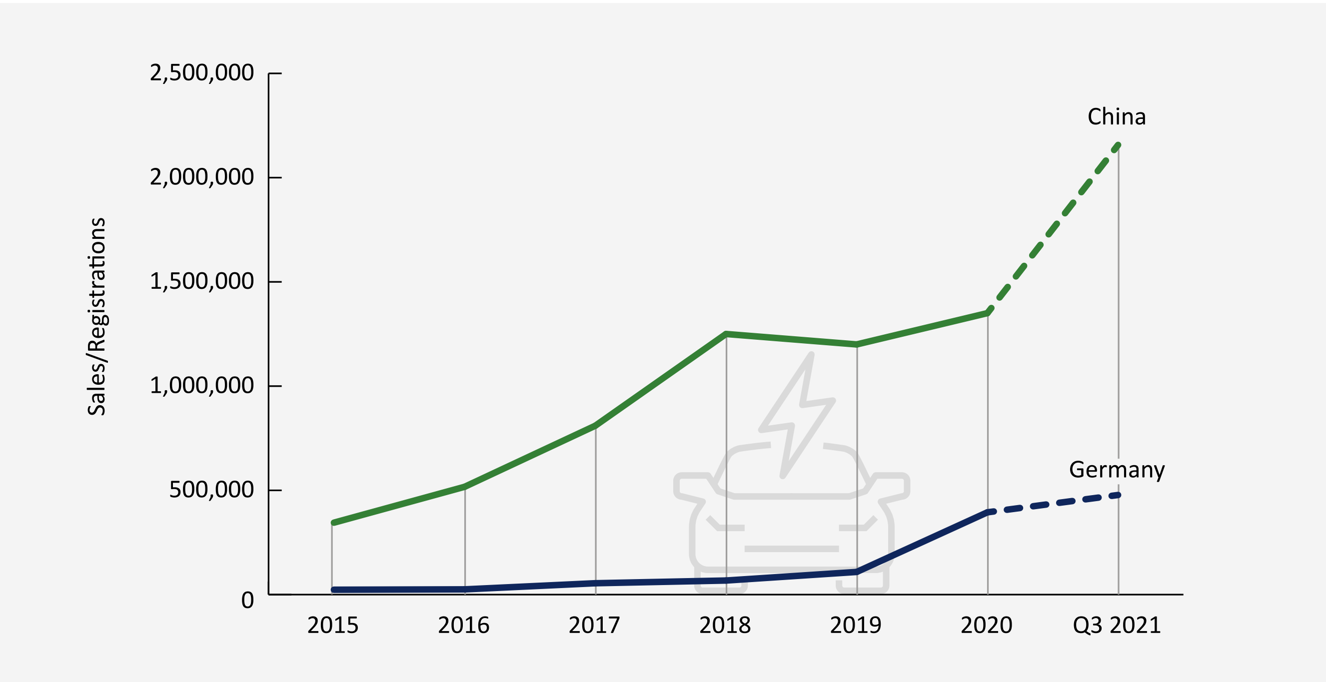

Figure 7: Sales figures for so-called New Energy Vehicles (NEVs) in China. The combined number of registrations of purely battery-powered vehicles and plug-in hybrid vehicles in Germany are shown for comparison. Data from 79 to 82.

78 Jin et al., 2021

79 KBA

80 Bönnighausen, 2021

81 Schaal, 2021

82 CAAM

83 Wang, 2021

3.1 Political requirements for regulating recycling in China

A concise summary of developments regarding regulations, measures, and standards for handling waste batteries from NEVs can be found in the publications from Li et al. as well as Wang.[84,85] The significant milestones of the described developments are illustrated in Figure 9.

The measures shown are only part of the politically initiated standards. In their publication from 2021, Zou and Liu refer to over 40 measures which are related to battery recycling and where published by various Chinese ministries and administrative organizations. Thus, China has an extensive package of measures to manage the recycling of waste batteries. However, it should be noted that most of these measures are not mandatory and furthermore that no clear financial incentives where put in place to implement these.[86,87] Therefore, these measures represent a versatile framework, which however is currently only partly binding and thus only being partially implemented.

3.2 The Chinese recycling industry is already well developed

There are over 3,000 companies in China which operate in the battery recycling sector.[88] However, it is unclear which of the measures described in Section 3.1 are specifically implemented by these 3,000 companies. In 2018 the Chinese Ministry for Industry and Information Technology (MIIT) published a so-called White List with companies that meet the criteria for the ***Industrial Standard Conditions for Comprehensive Utilization of Waste Power Batteries for***

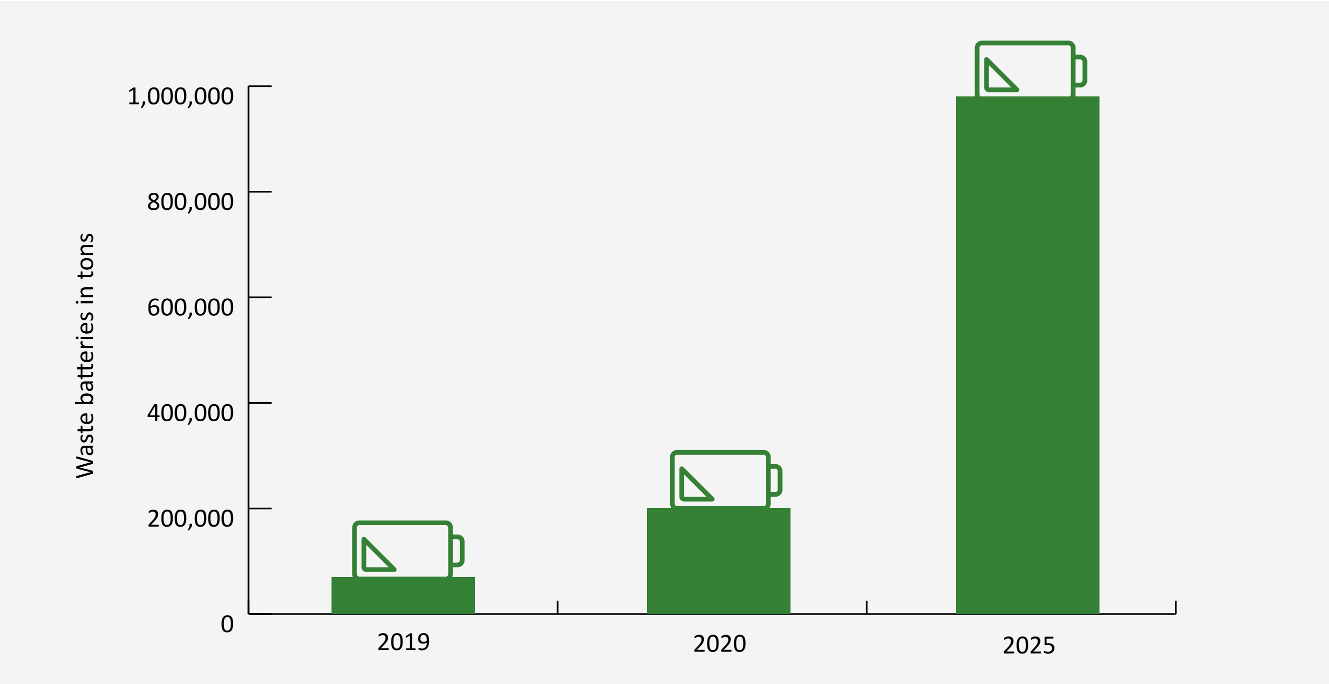

Figure 8: Expected returns of waste batteries in China. Data from 85.

84 Li et al., 2021

85 Wang et al., 2021

86 Zou, Liu, 2021

87 Li et al., 2021

88 Chen et al., 2021

New Energy Vehicles. The companies included in this list are distinguished by a high degree of automation, energy efficiency, environmental protection standards, efficient use of resources as well as advanced technologies and are of a certain scale. In 2018 five companies met the criteria. These five companies are Brunp, GEM, GHTech, Highpower Technology and Huayou Cobalt, which are briefly introduced in Table 2.

At the beginning of 2021 the MIIT published a second White List with 22 companies which meet the criteria for the *Industrial Standard Conditions for Comprehensive Utilization of Waste Power Batteries for New Energy Vehicles*[89]. The companies in this list operate or are planning to establish recycling plants and/or plants for processing waste batteries for second-life applications in various Chinese provinces. The new companies on this list include BYD, Ganfeng and CNGR, among others. These three companies are briefly introduced in Table 3.

Some of the specified recycling capacities of the White List companies described here are still under construction, however, they claim to have more than enough capacity to process the 200,000 tons of waste battery returns forecast

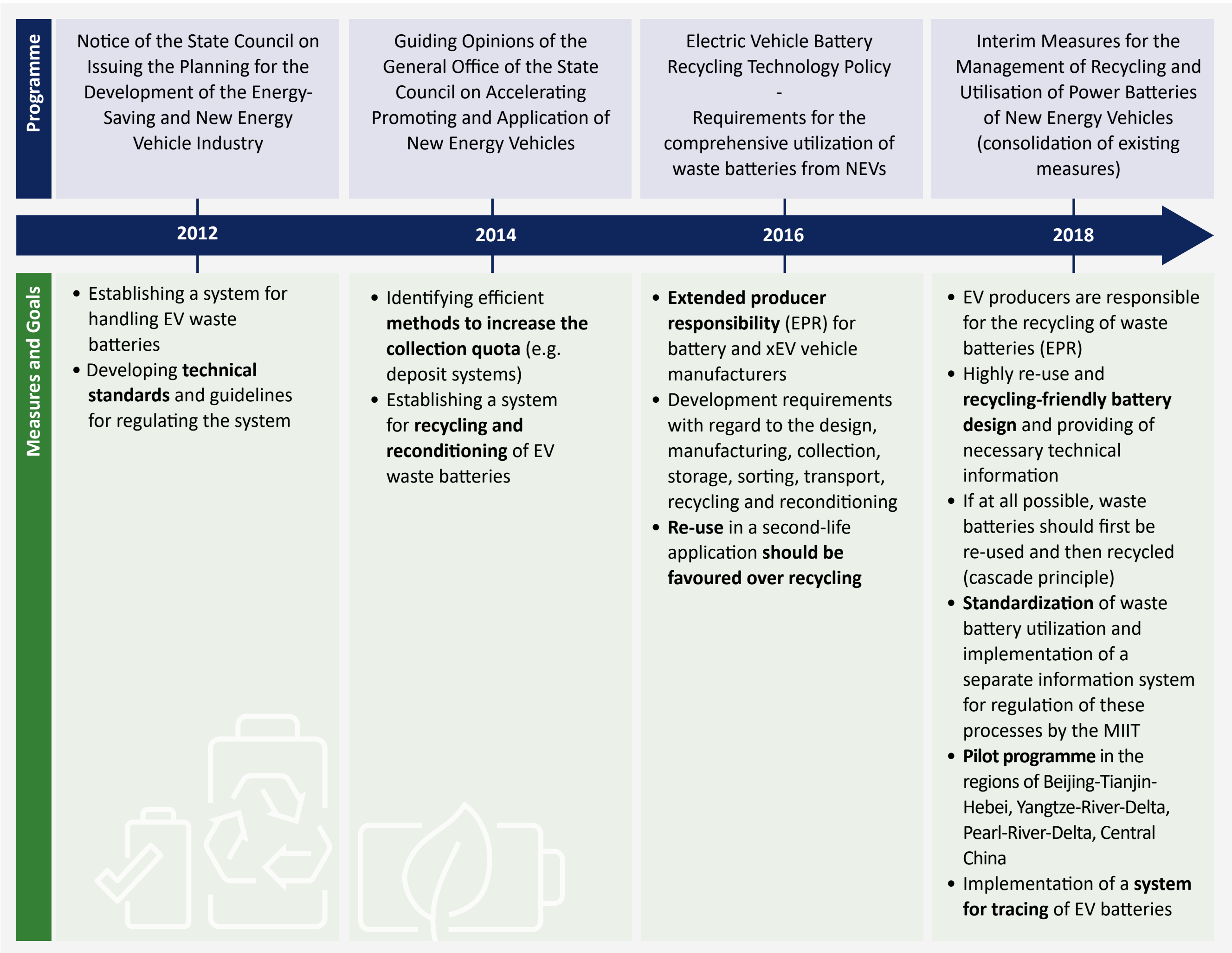

Figure 9: Regulations, measures and standards for managing battery recycling in China.

89 SMM, a

for 2020. That China has sufficent recycling capacity is also supported by current media reports.[90]

The stated JVs underscore the international orientation of the Chinese recycling companies. The JV between Huayou Cobalt and Posco, for example, is building a recycling plant in Gwangyang, South Korea to process black mass, some of which is also expected to come from European battery factories.[91] By establishing the JV and processing waste batteries in South Korea, it is possible to mitigate the effect of restrictions on importing of waste batteries to China in effect since 2017.

The explicit distinction between plants for refurbishing waste batteries for second-life batteries and recycling plants in the second White List underscores the high value placed on refurbishment of lithium-ion batteries in China. Typical Second-Life applications are applications where lead-acid batteries are replaced by lithium-ion batteries. One example are small electric vehicles in China which have a limited speed

Company	Founding year	Capacity [t/a]	Information
Brunp	2005	120,000	Subsidiary of CATL that claims to achieve a recycling rate of over 99% for nickel, cobalt and manganese.[a] CATL will invest the equivalent of 4.3 billion Euro jointly with Brunp, in order to build a battery recycling complex in Hubei with a recycling capacity of 300,000 t/a and attached material processing for the production of active materials.[b]
GEM	2001	200,000	In addition to recycling plants in China, GEM operates a joint venture with the South Korean active material producer Ecopro[c]. GEM claims that it has the capacity to dismantle 200,000 tons of waste batteries per year and to process up to 1.5 GWh for second-life applications.[d]
GHTech	1980	200,000	GHTech is also known as Guangdong Guanghua Sci-Tech. The GHTech-subsidiaries Zuhai Zhongli New Energy Sci-Tech and Zuhai Zhongli New Energy Sci-Tech are located in the Chinese city of Zuhai, where they perform battery recycling in addition to the processing of batteries for second-life applications. It has plans for sufficient capacity to recycle up to 200,000 tons of waste batteries per year at this location.[e]
Highpower Technology	2001	n/a	Highpower Technology has locations in the Chinese cities of Huizhou and Ganzhou. No information was available on the available recycling capacities[f]
Huayou Cobalt	2002	60,000	Huayou Cobalt operates a recycling-JV in partnership with the South Korean steel manufacturer and active material producer POSCO. Huayou Cobalt has a recycling capacity of 60,000 tons per year.[g]

References: a CATL b Yicai, a c YNA, a d GEM e GHTech f HPT g CES, a

Table 2: Companies of the MIIT White List from 2018

90 SMM, b

91 Huayou

and are in part powered by lead-acid batteries. Another market for second-life applications is storing of renewable energy from wind and photovoltaic systems.[92]

Another example is the use of refurbished lithium-ion batteries in the telecommunication infrastructure as backup power supplies for transmission stations. The Chinese company China Tower is dispensing with backup power supplies based on lead-acid batteries, and instead is deploying refurbished lithium-ion batteries. The demand for providing this backup power is approximately 54 GWh and thus holds great potential for second-life applications.[93]

3.3 Effects on Europe

With a projected volume of 200,000 tons of waste batteries by 2020, the Chinese recycling market has already reached a volume only expected for Europe after 2025.[94] In addition to waste batteries, the Chinese recycling industry is also supplied with waste material streams from the battery value chain and with defective batteries from recall campaigns. Thanks to the attained economies of scale, the Chinese recycling industry is already able to operate profitably today.[95]

The established measures for regulating battery recycling show that China aims to implement a sustainable battery recycling system. Even if not all of the Chinese recycling industry is committed to implementing the regulations, the companies on the White List in particular show that there are advanced players who meet sustainability criteria and are experienced in scaling up recycling plants. According to Melin et al. the Chinese companies are probably in a good position to meet the requirements of the draft of the new European Battery Regulation, such as e.g. recovery rates of over 90% for cobalt, nickel and copper (see. 2.2.2).[96]

Chinese companies can therefore be expected to establish themselves on the European recycling market. CNGR, for example, cooperates with the South Korean recycling company SungEel Hitech in order to explore the feasibility

Company	Founding year	Capacity [t/a]	Information
BYD	1995	n/a	BYD is a broad-based technology enterprise which, among other things, manufactures batteries and electric vehicles. BYD has been operating a battery recycling plant in Shanghai since 2018.[a]
Ganfeng Lithium	2000	n/a	In addition to raw material extraction and material production, Ganfeng Lithium is also active in the recycling field. Ganfeng operates a recycling plant in Xinyu.[b]
CNGR	2014	70,000	CNGR's core area of expertise is the manufacturing of cathode materials. The company supplies CATL and LG Chem, among others. It is planning construction of recycling plants in Ningxiang and Qinzhou with the capacity to recycle over 70,000 tons of waste batteries.[c]
References: a Reuters b Ganfeng c Yicai, b			

Table 3: Selected companies from the MIIT's second White List.

92 Liu et al., 2020

93 IDTechEx

94 Neef et al., 2021

95 Niese et al., 2020

96 Melin et al., 2020

of battery recycling in Europe.[97] SungEel Hitech, in turn, is a suitable partner for the European market since it already operates two recycling plants in Hungary.[98]

The signs that Chinese companies could establish themselves on the European market suggest a localization of supply chains. This localization is also supported by regulations to some degree. The draft of the new European Battery Regulation, for example, only calls for exporting of waste batteries if it is possible to prove that the exported batteries are recycled within the drafts framework conditions. As described in Section 3.2, exporting of waste batteries to China is impossible since the Chinese government prohibited importing of waste batteries in 2017. The import ban was tightened in 2021 and expanded to include all solid waste.[99] While it is possible to mitigate the consequences of the import ban through JV between Chinese and South Korean companies and by outsourcing the battery recycling to South Korea, legislative changes can also change these waste and material streams. The South Korean government, for example, is planning to restrict the import of industrial waste but clarifies that waste batteries are, among other things, exempt from this regulation.[100] Nevertheless, the export of waste batteries is supposed to be limited in the course of the K-Battery Development Strategy, which in turn could also affect the material flows to China.[101] The unknowns of future regulations could be avoided through localization of supply chains. CATL and BASF, for example, are striving to develop local supply chains and have established a strategic partnership for this purpose, in order to collaborate in Europe in the areas of cathode material and battery recycling.[102]

There are good indications that a local recycling industry will develop in Europe, which will benefit from the economies of scale of rapidly growing electric mobility and will be able to process waste batteries economically. This recycling industry is subject to global competition, however, so that advanced and efficient technologies which enable sustainable and economic recycling are essential for companies to succeed. Chinese companies will be strong competitors for emerging European battery recyclers due to the experience advantage they have already gained in their home market.

97 Yicai, c

98 HIPA

99 RI

100 YNA, b

101 CES, b

102 BASF

4 OUTLOOK

Sustainably produced batteries are a key technology for the transition to a modern, resource-efficient and competitive economy – in particular in the mobility and energy supply sector. The biggest contribution here will be made by batteries which are manufactured with the lowest possible environmental impact, using materials sourced and produced with full regard for human rights as well as social and ecological standards.

Tighter regulatory sustainability requirements support the goal of establishing a **circular economy for battery raw materials and components** in Europe under compliance with due diligence requirements as well as social and ecological standards. **Companies are under growing pressure to act**, not only from legislators but also from customers and investors who are increasingly demanding transparency with regard to sustainability.

A standardized sustainability metric is required to define and compare the sustainability of batteries. Indicators have already been developed for many sustainability aspects, however, not all developed sustainability indicators are equally relevant for the battery industry and shown to be effective in practice. The following aspects can be summarized for the individual main topics:

- **Environmental impacts**: Indicators to describe the environmental impacts exist. They already experience a high degree of operationalization in fields outside of the battery industry and can therefore be considered suitable for use in practice, even if their concrete application in battery cell production is currently provided for only occasionally in regulations or the draft of the new European Battery Regulation.

- **Circular economy & End-of-Life-Management**: Indicators for the circular economy and end-of-life-management exist. Some of these may only be applied in future regulations, so their feasibility for use in practice still needs to be determined.

- **Social considerations and human rights**: Indicators for social considerations and human rights exist and are not sector-specific. They exhibit a high degree of operationalization, but some indicators such as the forced labour indicator are difficult to measure in practice.

- **Working conditions**: Indicators on working conditions exist and are not sector-specific. They enjoy widespread use in practice and thus exhibit a high degree of operationalization.

A comparative look at the Chinese recycling economy reveals that a large number of regulations have been passed there to regulate the circular economy and end-of-life management. The indicators used there, such as e.g. the material recovery quotas, are partly similarly ambitious as those in the draft of the new European Battery Regulation.

However, the majority of the measures in China are non-binding, so that they are not fully implemented by the entire recycling industry. Since 2018 the Chinese Ministry for Industry and Information Technology published two lists with about 20 companies which meet the ***Industrial Standard Conditions for Comprehensive Utilization of Waste Power Batteries for New Energy Vehicles*** and which e.g. distinguish themselves by meeting high environmental protection standards. These leading companies are presumably well equipped to meet the requirements of the coming draft of the new European Battery Regulation as well.

It is therefore foreseeable that Chinese companies can meet the tighter European sustainability requirements, at least with regard to resource-efficient production. In addition, the first Chinese companies are currently exploring the possibility of establishing recycling plants in Europe. On the other hand, due to current import restrictions it is unlikely that the recycling of waste batteries will shift to China.

But since tightening of the European sustainability requirements goes beyond the circular economy aspect with regard to environmental impacts, social considerations and human rights, it remains to be seen whether Chinese battery cells can withstand the competitive pressure on the European Single Market.

REFERENCES

BASF
BASF. BASF und CATL unterzeichnen Rahmenvertrag, um globale Klimaneutralitätsziele schneller zu erreichen. [Online] retrieved on 03.01.2022

Bayerischer Industrie- und Handelskammertag e.V., 2020
Bayerischer Industrie- und Handelskammertag e.V. (2020). SDG-Wegweiser für kleine und mittlere Unternehmen- Ziele für nachhaltige Entwicklung.

Bechberger et al., 2021
Bechberger, M.; Vorholt, F.; Bünting, A.; Oehl-Schalla, N. (2021). Nachhaltigkeit der Batteriezellfertigung in Europa.

Beck, 2014
Beck (2014). Beck'scher Onlinekommentar-GG/Ruffert, 21. Edition, München 01.06.2014, Art. 12 Rn. 146.

Beermann, Vorholt, 2022
Beermann, V.; Vorholt, F. (2022). Marktanalyse Q4 2021.

BioLogic
BioLogic. Battery states: State of charge (SoC), State of Health (SoH). Electrochemistry basics series. [Online] Retrieved on 15.12.2021

BMZ, a
BMZ. Agenda 2030. [Online] Retrieved on 14.12.2021.

BMZ, b
BMZ. SDG 7: Bezahlbare und saubere Energie. [Online] Retrieved on 15.12.2021

BMZ, c
BMZ. SDG 9: Industrie, Innovation und Infrastruktur. [Online] Retrieved on 15.12.2021

BMZ, d
BMZ. SDG 6: Sauberes Wasser und Sanitäreinrichtungen. [Online] Retrieved on 15.12.2021

BMZ, e
BMZ. SDG 12: Nachhaltige/r Konsum und Produktion. [Online] Retrieved on 15.12.2021

BMZ, f
BMZ. SDG 15: Leben an Land. [Online] Retrieved on 15.12.2021

BMZ, g
BMZ. SDG 3: Gesundheit und Wohlergehen. [Online] Retrieved on 15.12.2021

BMZ, h
BMZ. SDG 8: Menschenwürdige Arbeit und Wirtschaftswachstum. [Online] Retrieved on 15.12.2021

Bönnighausen, 2021
Bönnighausen, D. (2021). eMobility-Dashboard September: 33.655 reine Elektro-Pkw. electrive. [Online] Retrieved on 20.12.2021

Bundesregierung, 2020
Bundesregierung (2020). Leitfaden der Bundesregierung für eine nachhaltige Textilbeschaffung der Bundesverwaltung.

Bundestag, 2009
Bundestag (2009). Gesetz über das Inverkehrbringen, die Rücknahme und die umweltverträgliche Entsorgung von Batterien und Akkumulatoren (Batteriegesetz- BattG).

Bundestag, 2020
Bundestag (2020). Erstes Gesetz zur Änderung des Batteriegesetzes- vom 3. November 2020

Bundestag, 2021
Bundestag (2021). Gesetz über die unternehmerischen Sorgfaltspflichten in Lieferketten.

CAAM
caam. China Sales of NEVs (2012-2020). [Online] Retrieved on 20.12.2021

CATL
CATL. Battery Recycling. [Online] Retrieved on 20.12.2021

CES, a
CES. POSCO to process battery production scrap from Europe in joint venture with Huayou Cobalt. [Online] Retrieved on 20.12.2021

CES, b
CES. South Korea launch national battery strategy – reuse and recycling in focus. [Online] Retrieved on 03.01.2022

Chalmers et al, 2021
Chalmers, J.; Picard, N.; Eastman, H.; Wilkinson, G. (2021). Global Investor Survey. PwC.

Charbonneau
Charbonneau, N. (2021). Kinderarbeit weltweit: Die 7 wichtigsten Fragen und Antworten. Unicef. [Online] Retrieved on 15.12.2021

Chen et al., 2021
Chen, J. et al. (2021). Status and Problems of Closed-Loop Supply Chain of Traditional Power Battery in China. In Proceedings of the Korean Institute of Information and Commucation Sciences Conference (pp. 567-569). The Korea Institute of Information and Commucation Engineering.

Deloitte
Deloitte. Verantwortung als Chance: das Transformationsthema Sustainability. [Online] Retrieved on 15.12.2021

DGUV, 2021
Deutsche Gesetzliche Unfallversicherung (DGUV): Arbeitsunfallgeschehen 2020, September 2021

DGVN
DGNV. Moderne Sklaverei und Zwangsarbeit. [Online] Retrieved on 15.12.2021

Dolega et al, 2020
Dolega, P.; Buchert, M.; Betz, J. (2020). Ökologische und sozio-ökonomische Herausforderungen in Batterie-Lieferketten: Graphit und Lithium.

Europäische Kommision, 2012
Europäische Kommision (2012). Verodnung (EU) 493/2012 mit Durchführungsbestimmungen zur Berechnung der Recyclingeffizienzen von Recyclingverfahren für Altbatterien und Altakkumulatoren gemäß der Richtlinie 2006/66/EG des Europäischen Parlaments und des Rates.

Europäische Kommision, 2019
Europäische Kommision (2019). COM(2019) 640 final- The European Green Deal.

Europäische Kommision, 2021
Europäische Kommision. Klima- und energiepolitischer Rahmen bis 2030. [Online] Retrieved on: 14.12.2021.

Europäische Union, 2012a
EU (2012). Richtlinie (EU) 2012/27 des Europäischen Parlaments und des Rates zur Energieeffizienz.

Europäische Union, 2012b
EU (2012). Leitlinien für die Berichterstattung über nichtfinanzielle Informationen (2017/C 215/01)

Europäische Union, 2017
EU (2017). Verordnung (EU) 2017/821 des Europäischen Parlaments und des Rates zur Festlegung von Pflichten zur Erfüllung der Sorgfaltspflichten in der Lieferkette.

Europäische Union, 2019
EU (2019). Verordnung (EU) 2019/2016 zur Festlegung eines Rahmens für die Energieverbrauchskennzeichnung.

Europäische Union, 2020
EU (2020). Verordnung (EU) über Batterien und Altbatterien, zur Aufhebung der Richtlinie 2006/66/EG und zur Änderung der Verordnung (EU) 2019/1020

Fink
Fink, L. Eine grundlegende Umgestaltung der Finanzwelt. BlackRock. [Online] Retrieved on 15.12.2021

Ganfeng
Ganfeng. Global Layout. [Online] Retrieved on am 03.01.2022

GBA, 2020
Global Battery Alliance. (2020). The Global Battery Alliance Battery Passport: Giving an identity to the EV's most important component.

GEM
GEM. Industry Chain of Waste Battery Recycling and Power Battery Material Manufacturing. [Online] Retrieved on 20.12.2021

GHTech
GHTech. Brief Introduction. [Online] Retrieved on 20.12.2021

HIPA
HIPA. SUNGEEL HITECH IS OPENING A NEW GLOBAL GREEN BATTERY RECYCLING PLANT IN BÁTONYTERENYE. [Online] Retrieved on 03.01.2022

HPT
HPT. Highpower Technology. [Online] Retrieved on 20.12.2021

Huayou
Huayou. Huayou Recycling Technology Co., Ltd. cooperates with POSCO to carry out the recycling and utilization of waste batteries in South Korea. [Online] Retrieved on 20.12.2021

IDTechEx
IDTechEx. China Tower can ‚absorb' 2 million retired electric vehicle batteries. [Online] Retrieved on 03.01.2022

IEA
IEA. Carbon capture, utilisation and storage. [Online] Retrieved on: 14.12.2021.

ILO
ILO. Safety and health at work. [Online] Retrieved on 15.12.2021

ILO & UNICEF, 2021
ILO & UNICEF (2021). Child Labour: Global estimates 2020, trends and the road forward.

ILO, 2012
ILO (2012). Hard to see, harder to count- Survey guidelines to estimate forced labour of adults and children.

Jin et al., 2021
Jin, L. et al. (2021). Driving a Green Future: A Retrospective Review of China's Electric Vehicle Development and Outlook for the Future. ICCT.

Jinasena et al., 2021
Jinasena, A; Burheim, O; Strømman, A. (2021). A Flexible Model for Benchmarking the Energy Usage of Automotive Lithium-Ion Battery Cell Manufacturing

KBA
KBA. Neuzulassungen von Personenkraftwagen in den Jahren 2011 bis 2020 nach ausgewählten Kraftstoffarten. [Online] Retrieved on 20.12.2021

Kees et al., 2020
Kees, J. et al. (2020). Consumer Products and Retail – How sustainability is fundamentally changing consumer preferences. Capgemini Research Institute.

König, 2021
König, J. (2021). SDG und ISO 50001: Nachhaltigkeitsziele erreichen. DQS. [Online] Retrieved on 15.12.2021

Kretschmer
Kretschmer, A. (2021). CCS: Was bedeutet Carbon Capture and Storage?. CHEMIE TECHNIK. [Online] Retrieved on 15.12.2021

Kühl, Petruschke
Kühl, A; Petruschke, P. (2021). Was die Solarpflicht für Unternehmen in Industrie & Gewerbe bedeutet. [Online] Retrieved on 15.12.2021

Lernhelfer
LERNHELFER. Sozialleistungen. [Online] Retrieved on 15.12.2021

Li et al., 2021
Treatment of electric vehicle battery waste in China: A review of existing policies. Journal of Environmental Engineering and Landscape Management, 29(2), 111-122.

Liu et al., 2020
Liu et al. (2020). Research on the Critical Issues for Power Battery Reusing of New Energy Vehicles in China. Energies, 13(8), 1932.

makeITfair, 2007
makeITfair (2007). Zinn verbindet Komponenten, aber spaltet lokale Gemeinden.

Melin et al., 2021
Melin et al. (2021). Global implications of the EU battery regulation. Science, 373(6553), 384-387

Neef et al., 2021
Neef et al. (2021). Recycling von Lithium-Ionen-Batterien: Chancen und Herausforderungen für den Maschinen- und Anlagenbau. Fraunhofer-Institut für System- und Innovationsforschung ISI.

Neißendorfer
Neißendorfer, M. (2021). Second Life oder Recycling? Wie eine neue Software gebrauchte E-Auto-Akkus bewertet. Elektroauto-News. DQS. [Online] Retrieved on 15.12.2021

Niese et al., 2020
Niese et al. (2020). The Case for a Circular Economy in Electric Vehicle Batteries. Boston Consulting Group.

Oxfam
Oxfam. Lieferkettengesetz: Für Menschenrechte in der Wirtschaft. [Online] Retrieved on: 14.12.2021.

REACH
REACH-Helpdesk. Die Verordnungen REACH und CLP im Überblick. [Online] Retrieved on 15.12.2021

Reuters
Reuters. Chinese carmaker BYD close to completing battery recycling plant. [Online] Retrieved on 03.01.2022

RI
Recycling International. China ends all waste imports. [Online] Retrieved on 03.01.2021

Schaal, 2021
Schaal, S. (2021). NEV-Verkäufe in China steigen weiter. electrive. [Online] Retrieved on 20.12.2021

SMM, a
SMM. Ministry of Industry and Information Technology: „New Energy vehicle waste Power Battery Comprehensive Utilization Industry Standard conditions“ Enterprise list (second batch). [Online] Retrieved on 20.12.2021

SMM, b
SMM. Accelerating the Recycling and Utilization of Power Battery, the Propulsion Agency is optimistic about the growth of the industry. [Online] Retrieved on 20.12.2021

SPD, BÜNDNIS 90 / DIE GRÜNEN, FDP, 2021
SPD, BÜNDNIS 90 / DIE GRÜNEN, FDP (2021). Koalitionsvertrag 2021 – 2025 zwischen der SPD, BÜNDNIS 90 / DIE GRÜNEN und den Freien Demokraten (FDP).

Umwelt Bundesamt, 2020
Umwelt Bundesamt. Marktdaten: Bereich Sonstige Konsumgüter. [Online] Retrieved on 15.12.2021

Umwelt Bundesamt, 2021
Umweltbundesamt. Energieverbrauchskennzeichnung. [Online] Retrieved on 15.12.2021

UNECE
UNECE. Major auto markets join forces for draft UN legislation on electric vehicle battery durability. [Online] Retrieved on: 14.12.2021.

United Nations, 2019
United Nations (2019). Mineral resource governance.

UNRIC, a
UNRIC. Ziel 9: Eine widerstandsfähige Infrastruktur aufbauen, breitenwirksame und nachhaltige Industrialisierung fördern und Innovationen unterstützen. [Online] Retrieved on 15.12.2021

UNRIC, b
UNRIC. Allgemeine Erklärung der Menschenrechte. [Online] Retrieved on 15.12.2021

Wang, 2021
Wang, D. (2021). Research on policies of power batteries recycle in China from the perspective of life cycle. Journal of Environmental Engineering and Landscape Management, 29(2), 135-149.

Wittpahl, 2020
Wittpahl,V. (2020). Klima.

Wolf et al, 2021
Wolf, I.; Fischer, Dr. A.; Huttarsch, J. (2021). Soziales Nachhaltigkeitsbarometer der Energie- und Verkehrswende. Ariadne Projekt. [Online] Retrieved on 15.12.2021

World Economic Forum, 2019
World Economic Forum (2019). A Vision for a Sustainable Battery Value Chain in 2030- Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation.

Yicai, a
Yicai. CATL Starts Work on USD5 Billion Industrial Park in China's Hubei Province. [Online] Retrieved on 20.12.2021

Yicai, b
Yicai. China's CNGR Unit to Invest USD202 Million to Lift Ternary Precursor Output, Build Battery Recycling Plant. [Online] Retrieved on 04.01.2022

Yicai, c
Yicai. China's CNGR Soars as It Teams With South Korea's SungEel to Recycle EV Batteries in Europe. [Online] Retrieved on 03.01.2022

YNA, a
YNA. S. Korean-Chinese joint venture to build plant for cathode materials for lithium-ion batteries. [Online] Retrieved on 20.12.2021

YNA, b
YNA. S. Korea to phase out industrial waste imports. [Online] Retrieved on 03.01.2022

ZEIT ONLINE
ZEIT ONLINE (2021). EU-Staaten verpflichten sich auf konkrete Sozialziele. [Online] Retrieved on 15.12.2021

Zou, Liu, 2021
Zou, R.; Liu, Q. (2021). Current situation and Countermeasures of power battery recycling industry in China. In IOP Conference Series: Earth and Environmental Science (Vol. 702, No. 1, p. 012013). IOP Publishing.

TABLE OF FIGURES

LIST OF ABBREVIATIONS

BEV	Battery Electric Vehicle
BMS	Batterie Management System
CLP	Classification, Labelling and Packaging of Chemicals
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GBA	Global Battery Alliance
GHG	Green House Gas
GRI	Global Reporting Initiative
GTR	Globale Technische Regelung (engl.: Global Technical Regulation)
ILO	International Labour Organisation
ISO	International Organization for Standardization
JV	Joint Venture
AI	Artificial Intelligence
KPI	Key Performance Indicator
MIIT	Ministry for Industry and Information Technology
NEV	New Energy Vehicle
PSILCA	Product Social Impact Life Cycle Assessment Database
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SDG	Sustainable Developement Goals
SoC	State of Charge
SoH	State of Health
UN	United Nations
UNECE	United Nations Economic Commission For Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IHE	UNESCO Institute for Hydrological Education
WFN	Water Footprint Network
WHO	World Health Organization
xEV	x Electric Vehicle (x = Battery, Plug-In Hybrid oder Fuel Cell)