日独エネルギーパートナーシップチーム
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DEUTSCHLAND – JAPAN

## Overview Study

# Circular economy solutions for critical raw materials for the energy transition

*Opportunities for German-Japanese cooperation*

*Prepared as part of the bilateral energy partnership on behalf of the German Federal Ministry for Economic Affairs and Climate Action*

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# Opportunities for German-Japanese cooperation

# Content

# 1 Executive summary

As like-minded and long-standing partners in climate and energy policy cooperation, Germany and Japan have both recognized the potential of circular solutions to secure access to raw materials crucial for the energy transition while simultaneously reducing the carbon footprint of energy transition technologies. The underlying study analyses the countries' respective circumstances, existing policy approaches as well as needs and challenges for this undertaking. It then highlights similarities and differences in country approaches, as well as opportunities for mutual learnings and cooperation within and beyond the Japanese-German Energy Partnership. This study focuses on policy measures to secure selected critical minerals and raw materials for key technologies for the energy transition, obtained through desktop research and insights from industry experts. The authors note limitations due to the evolving geopolitical and economic context affecting the findings.

In order to meet their respective climate and energy goals, both Germany and Japan need to ramp up their production and installation of key energy transition technologies, including wind turbines (onshore and offshore), solar photovoltaics, battery storage and electrolyers (for the production of hydrogen). Both countries have pledged to undertake efforts to triple global renewable energy capacity by 2030 as part of the COP28 agreement of 2023. This will require significant amounts of so called critical raw materials that are essential for the production of the aforementioned technologies. As part of the communiqué of the G7 Ministerial Meeting on Climate, Energy and Environment in Sapporo in 2023, both countries also committed to strengthening the supply and circular economy along the global supply chains of these critical minerals and raw materials in order to minimize the environmental and social footprint of energy transition technologies while reducing pressure on primary sources. In doing so, both Japan and Germany recognize the potential that circular economy approaches such as "reduce by design", "repurpose", "repair" and "recycle" have for the sustainable supply of critical raw materials for the energy transition.

Various policy strategies and frameworks in both countries already include provisions to strengthen resource efficiency and circular economy approaches, aiming to reduce vulnerabilities and emissions related to raw material extraction. Germany and Japan are both generally well positioned in the areas of recycling and waste infrastructure. However, there is still room for progress with regard to the recovery of critical raw materials and the further development of targeted circular solutions for specific energy transition technologies.

Japan made an early political commitment to promoting resource efficiency and circular economy approaches, initially focusing on recycling, and later including other circular business models. Many Japanese companies are among the pioneers in high-quality recycling processes. Approaches such as the circular design of solar photovoltaics and batteries in particular are also being explored.

In Germany, too, the political focus has so far been strongly on promoting recycling, while extended producer responsibility systems with approaches such as end-of-life take-back have been established for product groups such as batteries. Initial approaches to circular design and new circular business models such as reuse or remanufacture are not only being piloted by German companies, but are also being politically promoted in initial guidelines. Various recently adopted European directives may lead to the future implementation of innovative approaches such as digital product passports and uniform design standards for improved recyclability, reusability and durability of e.g. batteries and solar photovoltaics. Both, in Japan and in Germany, however, only a few initiatives have so far been implemented in relation to the equally important energy transition technologies of wind turbines and electrolyzers.

In summary, both countries have begun to introduce legislation to improve the circularity of critical raw materials relevant for the energy transition. This can be read as an acknowledgement of the necessity for more comprehensive action. A more targeted proactive approach would ensure that discarded critical raw materials from energy transition technologies are readily available for domestic recycling and reuse in the future. Recent legislative developments are essential in securing a sustainable supply of critical raw materials, pivotal for both countries' transition to cleaner energy supply and the broader adoption of circular economy principles.

The initial analysis and comparison of both countries policies reveals key opportunities for Japan and Germany to enhance their circular economy strategies for securing critical raw materials needed for the energy transition. By learning from each other's practices, they can:

- **Recycle:** Mandate the use of recycled materials in energy technologies and enhance R&D for advanced recycling of complex devices.
- **Reuse/Reduce:** Implement criteria for the circular design and material substitution, particularly in photovoltaics, to minimize raw material use.
- **Promote Circular Markets**: Use sustainable/circular procurement and trade policies to foster markets for

circular technologies, including wind turbines and electrolyzers.

Further collaboration within the Japanese-German Energy Partnership and broader international frameworks can amplify these efforts globally, ensuring a more sustainable and secure raw material supply.

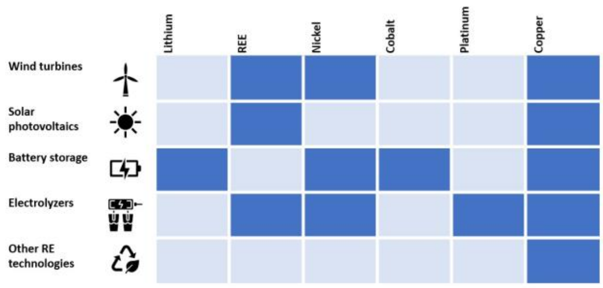
# 2 Introduction

## 2.1 Background: The role of critical raw materials in the energy transition

In 2015, at the United Nations (UN) Climate Change Conference (COP21) in Paris, all parties of the UN Framework Convention on Climate Change (UNFCC) agreed on the common goal of limiting the global temperature rise to below 2° Celsius compared to pre-industrial levels. In order to achieve this and the more ambitious 1.5° target, energy systems around the world are transitioning to renewable technologies (IEA 2022b). COP28, held in Dubai in 2023, concluded with a commitment from all parties to make efforts to triple renewable energy capacity worldwide by 2030 (UNFCC 2023).

As a result, production and demand for key technologies for renewable power, battery storage and hydrogen are increasing worldwide. In order to focus this study on the technologies of key importance for the energy transition in Japan and Germany, the following sections concentrate on **wind turbines, solar photovoltaics (PVs), battery storage** and **electrolyzers**. A number of so-called "critical" and "strategic" raw materials[1] are required for the production of these systems. The International Energy Agency (IEA) expects total mineral demand for clean energy technologies to double by 2040 under current policy plans in the energy sector and quadruple in a scenario to meet the Paris Agreement targets (IEA 2022b). Accordingly, the communiqué of the 2023 G7 Ministers' Meeting on Climate, Energy and Environment in Sapporo, Japan, emphasizes the central importance of strengthening "critical minerals" and materials supply for achieving a net-zero economy (MOE 2023). The definition of which materials are considered "critical" for the energy transition is not static and changes according to subjective and site-specific "economic, geopolitical and technological factors" (IRENA 2023). By screening 35 different lists of "critical materials", the International Renewable Energy Agency (IRENA) comes to the conclusion that 51 materials that are needed for the energy transition are mentioned on at least one of the lists (IRENA 2023). Based on the qualitative analysis of several studies on "critical raw materials" (CRMs) for the energy transition, this study provides an exemplary selection of six materials that can be highlighted as particularly relevant for the selected energy transition technologies described above: **lithium, rare earth elements (REEs), nickel, cobalt, platinum** and **copper** (CISL and Wuppertal Institute 2023; Systemiq 2022; Simas et al. 2022).

**Figure 1: Use of selected CRMs by energy transition technologies covered in this report**




Source: Own illustration based on Simas et al. 2022, using additional data form IEA 2022b; Kowalski and Legendre 2023

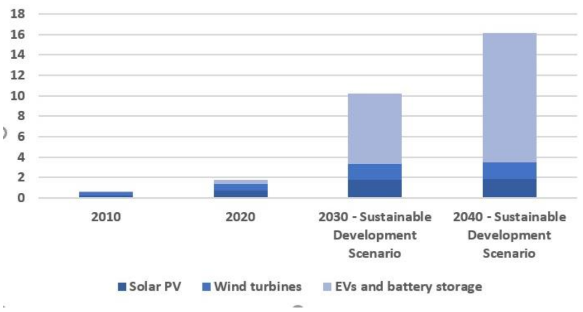
The specific types and quantities of materials required can vary significantly across the spectrum of clean energy technologies and even within a particular technology (IEA 2022b). That said, it is evident that the mineral intensity for **REE**s is particularly high for wind energy technologies. The increasing market for wind turbines utilizing permanent magnets, especially for offshore installations is expected to significantly boost the demand for REEs in the upcoming years and decades (IEA 2022b). In solar PV, different materials are used in different quantities depending on the module type, with crystalline silicon-based types currently being the most common PV technology. The IEA estimates that ongoing innovations could contribute to a reduction in the mineral intensity of PV modules in the long term and, in particular, dampen demand for silicon. At the same time, the expansion of alternative PV technologies could lead to a tripling of demand for **copper** from the industry by 2040 (IEA 2022b). Even though copper is often not included on CRM lists, it is essential for almost all green energy/low-carbon technologies, making it one of the potential bottleneck materials for the energy transition (Simas et al. 2022; Kowalski and Legendre 2023). Demand for **batteries** is being driven on the one hand by the growing need for storage systems for renewable energy installations, and on the other hand by the shift towards electric vehicles. Similar to PV, the need for specific materials varies considerably depending on the battery technology. For the last decade, lithium-ion batteries were dominant, in which **lithium**, **nickel** and **cobalt** play an important role (IEA 2022b). Due to the

[1] While all the technologies described require metals and alloys that are obtained by processing mineral-containing ores (IEA 2022b), for the sake of simplicity, the term "critical raw materials" (CRMs) is used in this report to represent the entire supply and value chain of relevant input materials.

increasing demand for and use of hydrogen, electrolyzers and fuel cells are also expected to experience significant expansion. Combined, these technologies may lead to increased demand for CRMs such as **nickel** and **platinum**, but the impact on the market will depend on the proliferation of different types of electrolyzer (IEA 2022b). In addition, so called “bulk materials” such as iron/steel and aluminium, which have already been used in many energy technologies for centuries, continue to play an essential role, as they make up to around one-third of all future demand for the transformation to a low-carbon economy (Simas et al. 2022; Kowalski and Legendre 2023).

While it is difficult to precisely calculate the future quantities of materials required due to many unknown factors, overall, the IEA estimates that in a scenario where the Paris Agreement targets are met, total demand for key materials will rise to over 40 % for copper and REEs, 60-70 % for nickel and cobalt and close to 90 % for lithium within the next two decades (IEA 2022b).

**Figure 2: Total mineral demand (Mt) from selected clean energy technologies by scenario, 2010-2040**




Source: Own illustration based on IEA 2022b

IRENA is already predicting a "mismatch between supply and demand" for some of these key minerals, especially lithium (IRENA 2023). It has to be highlighted, however, that future demands for certain CRMs also strongly depend on technological choices: different chemistries e.g. for rechargeable batteries use more or less CRMs. Simas et al. (2022) foresee that by shifting to different/new technologies, demand for seven raw materials critical to the energy transition (lithium, cobalt, nickel, manganese, REEs, platinum and copper) can be reduced by 30 % between 2022 and 2050. For example, switching to various chemistries for electric vehicle batteries and steering away from lithium-ion batteries for stationary uses could decrease the overall demand for cobalt, nickel, and manganese by 40-50% of the projected cumulative demand. compared to current technologies and business-as-usual-scenarios (Simas et al. 2022).

The mining and processing of many CRMs mentioned are highly concentrated geographically. For example, Australia dominates the mining of lithium, Chile is leading in the mining of copper and lithium. China (graphite, REEs), the Democratic Republic of the Congo (cobalt), Indonesia (nickel) and South Africa (platinum, iridium) also play central roles in the mining of some CRMs. In addition, China dominates mineral processing, currently accounting for 100 % of global refined supply of natural graphite and dysprosium (a REE important for wind turbines). In addition, 70 % of the refined supply of cobalt and 60 % of the supply of lithium and manganese are produced in China (IRENA 2023).

This creates strong dependencies and increases the risk of supply chain disruptions[2] and unstable prices. Geopolitical tensions could significantly slow down the progress of the energy transition in many countries. Governments around the world have therefore developed strategies in recent years to secure their access to CRMs in the future, including the promotion of circular economy (CE) solutions and approaches (IRENA 2023).

In addition, the extraction and processing of many CRMs is associated with high greenhouse gas (GHG) emissions and risks of social and environmental damage. The International Resource Panel (IRP) estimates that raw material processing and extraction accounts for 50 % of all GHG emissions and over 90 % of global water stress and land-use-related biodiversity loss (IRP 2020). The production of the important CRM copper alone currently accounts for 0.2 % of global anthropogenic GHG emissions. Given the expected increase in demand over the coming decades, some estimates suggest that this contribution could rise to as much as 2.7% by 2050 (The Copper Mark 2024).

However, a clean energy transition aims to decouple the increasing demand for materials for the expansion of renewable energy technologies from GHG emissions and other negative environmental and social impacts. This makes the responsible and sustainable procurement of materials an essential prerequisite for achieving international climate targets. As described in more detail in chapter 4, the increased use of circular concepts is a key lever to reducing the need for new primary materials and the associated GHG emissions linked to their extraction and processing (EEA 2024).

[2] The risk of supply bottlenecks due to geopolitical tensions is illustrated by the Chinese government's latest export restrictions. In October 2023, Beijing announced that export licences will be required for certain graphite products to “protect national security”. As China dominates 90 % of global graphite processing, this may lead to global graphite shortages. The restrictions are described in part as a response to increased pressure from numerous foreign governments on Chinese companies over their industrial practices (Liu and Patton 2023).

## 2.2 Objective and structure

This study aims to provide an overview of the current challenges and approaches for the implementation of CE approaches to ensure the most sustainable securing of CRMs for a clean energy transition in Japan and Germany. It seeks to identify overlaps, potential for increased cooperation and mutual learning, and to formulate recommendations.

The study first provides an overview of the role of various CRMs in achieving climate and energy policy targets in Germany and Japan and outlines the strategies that both governments have formulated to secure their access to the relevant CRMs in the future (chapter 3). The potential of CE approaches to secure CRM for key technologies of the energy transition and lower the overall GHG emissions in the production of these energy transition technologies is then presented and an overview of existing policy instruments in Germany and Japan that aim to promote or strengthen CE approaches in this context is given. Chapter 4 also presents selected industry best practices from Japan and Germany, which are already successfully applying some CE strategies for CRMS in energy transition technologies. Chapter 5 provides an overview of forums in which both countries are already working closely together on issues relating to the security of supply of CRMs. In chapter 6, a comparative perspective identifies common challenges and approaches for the promotion and disruption of CE approaches to securing CRMs for the energy transition in both countries and highlights differences and challenges. Building on the previous chapters and a conclusion, chapter 7 concludes with recommendations for topics for intesified cooperation between Japan and Germany on the topic.

This study was prepared by adelphi with the kind support of the German Chamber of Commerce and Industry in Japan (AHK Japan), the Institute for Global Environmental Strategies (IGES) and the team of the Japanese-German Energy Partnership. The results of the 13th German-Japanese Environment and Energy Dialogue Forum (EEDF), the annual policy flagship event of the Japanese-German Energy Partnership, which took place from 25 to 26 January 2024 in Kawasaki, Japan, were also incorporated into the finalization, in particular the conclusions and recommendations for topics of future German-Japanese cooperation.

# 3 Critical raw materials and the energy transition

## 3.1 Germany

### 3.1.1 Background of Germany's energy policy

Germany aims to achieve climate neutrality by 2045. In comparison to 1990 levels, greenhouse gas (GHG) emissions should be lowered by a minimum of 65 % by 2030 and at least 88 % by 2040 (BMU 2021). In order to achieve this, the German Renewable Energy Sources Act (EEG) sets a target of an 80 % share of renewable energies in Germanys gross electricity consumption by 2030 (BMWK 2022b). To this end, the annual gross expansion of wind power and PV is to increase significantly. The German government has set an expansion target for **offshore wind** energy of at least 30 gigawatts (GW) by 2030, 40 GW by 2035 and at least 70 GW by 2045 (The Federal Government 2024). For **onshore wind** power, the objective is 115 GW by 2030. From 2040 and beyond, the installed capacity is to increase to 160 GW (Bundesnetzagentur 2023). Expansion rates for **PV** systems are to increase to a total of 215 GW by 2030 (The Federal Government 2024) and 400 GW from 2040 onwards (BMWK 2023b).

In 2023, the **share of renewable energies** of public net electricily generation in Germany was 59.7 % (equalling a share of 57.1 % of renewables in the load). With a share of around 32 % of net public electricity generation (onshore and offshore combined), wind energy was the most important renewable energy source. PV, the second largest renewable energy source, accounted for approximately 12.5 % (Fraunhofer ISE 2024).

Additionally, to facilitate the integration of a higher share of volatile renewable energies, energy storage systems, such as **batteries**, hydrogen or thermal storage, will play an important role for the energy system of the future. To further support the ramp-up of electricity storage, the BMWK published an electricity storage strategy in December 2023, which outlines the BMWK's intended activities in the field of electricity storage (BMWK 2023c). In addition, the Federal Ministry of Education and Research (BMBF) published an "umbrella concept" for battery research in 2018 (updated in 2023), which describes the necessary federal funding measures in research and development to establish a technologically sovereign, competitive and sustainable battery value chain for Germany and Europe (BMBF 2023a). The concept also refers to another key area that will drive up demand for batteries in the coming years: The decarbonization of road transport, especially electric vehicles (EVs). Germany is aiming for 15 million EVs by 2030 (Die Bundesregierung 2022).

In addition, the German government published a National Hydrogen Strategy in 2020, which was updated in July 2023. The strategy is intended to form the basis for the future production, transportation and use of hydrogen in Germany. The strategy formulates the goal of achieving at least 10 GW of hydrogen **electrolyzer** capacity by 2030 (BMBF 2023b).

### 3.1.2 The role of CRMs in Germany's energy transition technologies

As described in chapter 2, an exact estimate of the future national demand for CRMs to achieve the expansion targets for new energy technologies described in chapter 3.1.1 is proving difficult, partly due to the large number of different technologies with different raw material requirements currently on the market. In addition, some CRMs may be imported to Germany and used in energy technologies that are subsequently exported again. Nevertheless, some estimates offer a general idea of the future demand for CRMs for the energy transition, of which a few selected figures are presented below for illustrative purposes.

In order to achieve the target of 215 GW of installed **PV** capacity by 2030, the German Raw Materials Agency (DERA) estimates that a large number of CRMs will be required for the necessary remaining expansion of 161 GW (based on installed capacity in 2022). These include **copper** (730 kt) and silicon (600 kt), gallium (12 t), germanium (25 t), tellurium (170 t) and indium (45 t). The listed raw materials are largely mined in China (DERA 2022a).

Based on the combined target for the expansion of **offshore and onshore wind energy** of 145 GW by 2030, DERA estimates that around 82 GW will need to be added without repowering of existing wind turbines. This will potentially require CRMs such as **REE**s (5.5 kt), whose global production is dominated by China, and chromite (40 kt), which is mainly mined in South Africa (DERA 2022b).

Furthermore, the increased demand for **batteries** in the mobility sector, grid storage and home storage is driving demand for CRMs in Germany. According to scenario-based calculations by the Öko-Institut and Prognos (2019) the future demand for lithium-ion batteries between 2018 and 2030 will require a cumulative amount of at least 74,000 tons of **cobalt** and 50,000 tons of **lithium** (Öko-Institut and Prognos 2019).

With regard to the expansion of the three most relevant **electrolysis** technologies[3] for the production of hydrogen, the research institute Ffe (2022) estimates an annual demand for 168,000 tons of nickel, 15 to 16 tons of platinum and 20 to 267 tons of iridium per year. This is based on a necessary global annual electrolyzer installation rate of over 400 GW for the period from 2040 in order to achieve the 1.5° target by 2050 (Ffe 2022; IRENA 2021).

In order to meet the above-mentioned demands for the most important CRMs for energy transition technologies, Germany and the EU as a whole are currently dependent on imports from third countries, as local capacities for primary extraction andmining, refining and processing are still very low (Carrara et al. 2023) and not all raw materials required can be found in Germany or the EU (CISL and Wuppertal Institute 2023; Die Bundesregierung 2023b). For 14 of the 27 raw materials declared as "critical" by the EU, both Germany and Europe are 100 % dependent on imports, and for three others import dependence is at over 95 % in each case. In addition, there are seven raw materials for which Germany is completely dependent on imports, while the EU as a whole is at 80 % dependent (Menkhoff and Zeevaert 2022; BGR 2022).

These dependencies have been recognized as potential vulnerabilities and as a risk factor for the successful expansion of energy transition technologies, so that in recent years policies and strategies have been formulated to secure Germany's and Europe's future access to CRMs.

### 3.1.3 Policy framework for securing raw materials supply

In Germany, the responsibility for ensuring the security of raw materials supply has traditionally rested with companies. There has been no governmental investment in mining companies, no establishment of national stockpiles, and no development of national mining projects. This approach was also reflected in the Federal Government's **first Raw Materials Strategy** launched in 2010. The strategy was developed following the publication of the European Commission's (EC) Raw Materials Initiative in 2008, which focused on strengthening trade and investment measures to secure access to raw materials, but also emphasized the potential of recycling and resource efficiency. Recognizing the limitations of a purely market-driven approach, in 2019 the German government formulated a new **Raw Materials Strategy** (BMWi 2019), which was adopted in 2020. The aim of the Raw Materials Strategy is to support companies in ensuring a secure and sustainable supply of raw materials. In this way, a raw material focused policy, as part of industrial policy, should contribute to strengthening the competitiveness of the German industry. The strategy also addresses the climate policy benefits that result from reducing the demand for primary raw materials in Germany, for example by encouraging the circular economy. The current Raw Materials Strategy consists of 17 concrete measures. The measures address three key areas of Germany's raw materials supply: (1) strengthening the domestic extraction of raw materials, (2) supporting the import and (3) recovering raw materials through increased recycling activities (see chapter 4.1 for more details). The strategy incorporates some of the successful measures from the first Raw Materials Strategy of 2010 and develops them further, including the guarantees for untied financial loans (UFK guarantees), the raw materials monitoring of the DERA (see chapter 4.1.2 for more details) and the establishment of Raw Materials Competence Centers at the Chambers of Commerce in selected countries rich in raw materials. In addition, a number of new measures were adopted, such as Research & Development (R&D) funding for projects on raw materials processing and lightweight construction. These include the establishment of a Dialogue Forum with the aim of working out concrete measures together with industry, science and administration to increase the use of secondary mineral raw materials from recycling. In the case of metals and industrial minerals, improved recycling management in particular is described as a key approach to reduce companies' dependence on raw material imports from abroad and at the same time to meet the requirements of responsible sourcing of raw materials (BMWK 2020).

The 2020 Raw Materials Strategy makes specific references to the list of CRMs first published by the EC in 2011 (followed by updated editions in 2014, 2017 and 2020 with a revised methodology). In the 2023 edition of the EC CRM list, 34 raw materials were included, more than twice as many as in the first list (EC n.d.a). The 2020 German Raw Materials Strategy also provides for close cooperation between the German government and the EC on issues relating to the future supply of raw materials (BMWi 2019).

In 2022, the BMWK prepared a paper (**Eckpunktepapier**) entitled "Ways to a sustainable and reliable raw material supply" (BMWK 2022a) to complement and refocus the 2020 Raw Materials Strategy. It comprises three central approaches: (1) CE, resource efficiency and recycling, (2) diversification of raw material supply chains, (3) ensuring a fair and sustainable market framework.

Due to the close link between German raw materials policy and decisions at European level, the new **Critical Raw Materials Act** (CRMA), which came into force in April 2024 as Regulation (EU) 2024/1252, could also play a central role in the future (Chee and Blenkinsop 2023; Council of the EU 2023; European Parliament and Council of the EU 2024a). The CRMA establishes a list of 34 CRMs, including 16 strategic ones, which are crucial for technologies such as green energy and are subject to potential supply chain risks. The regulations aims to boost the EU's self-sufficiency in strategic raw materials by setting objectives to expand its

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[3] The alkaline electrolysis (AEL), polymer exchange membrane electrolysis (PEMEL) and solid oxide electrolysis (SOEL).

production and recycling capacities domestically. The EU also aims to diversify CRM suppliers (for each strategic raw material, no single third country outside of the EU should supply more than 65 % of the EU's total consumption) and to introduce measures to increase the circularity and sustainability of the CRMs consumed in the EU (Council of the EU 2023; European Parliament and Council of the EU 2024a). All EU Member States are obliged to adopt and implement national programs with measures to achieve the common benchmarks formulated at EU level within two years of the regulation coming into force (i.e. by early 2026). Chapter 5, section 1, Article 26 of the regulation also sets out specific requirements with regard to national measures on circularity. To this end, a Board is to be set up as a governing structure in which Member States and the EC will jointly advise and coordinate the implementation of the CRMA's measures (Council of the EU 2023; European Parliament and Council of the EU 2024a).

## 3.2 Japan

### 3.2.1 Background of Japan’s energy policy

In October 2020, Japan committed to carbon neutrality by 2050 and raised its 2030 greenhouse gas reduction target to 46 % from 2013 levels (IRENA 2022). Supporting these ambitions, the industrial policy called **Green Growth Strategy Through Achieving Carbon Neutrality** (2021), aims to drive economic growth alongside environmental protection (METI 2021b). This strategy identifies 14 key sectors, including offshore wind power, solar, hydrogen, fuel ammonia, and nuclear power (METI 2023a).

Japan's **Strategic Energy Plan**, guided by the **Basic Act on Energy Policy** (entered into force in 2002), aims to balance energy security, economic efficiency, and environmental sustainability (S+3E policy) (METI 2021a). Enacted in 2021, it targets 36-38 % renewable energy by 2030, of which 14 to 16 % should come from **solar PV** and 5 % from **wind power**; the remaining coming from hydropower (11 %), biomass (5 %) and geothermal energy (1 %) (IEA 2023; ANRE 2022). To this end, Japan has set an expansion target for **solar PV energy** to reach between 103.5 and 117.6 GW of installed capacity by 2030 (ANRE 2021a). In terms of its wind power capacity, a fixed target of achieving 10 GW for **offshore wind** power has been set (ANRE 2021a), which includes a focus on developing floating offshore wind power plants. In 2022, renewables accounted for 22.7 % of Japan's total annual electricity demand, (ISEP 2023). Of this, 9.9 % was attributable to **PV** and 1 % to **wind** energy (ISEP 2023).

Batteries are crucial for achieving 2050 carbon neutrality, electrifying vehicles, and balancing renewable energy supply (METI 2022a). They also provide vital backup for critical infrastructure like 5G and data centers, bolstering digital society's resilience (METI 2022a). **METI's Battery Industry Strategy** (2022) aims for 24 GWh of storage batteries by 2030 and to increase Japan's battery production capacity to 150 GWh (METI 2022c). The strategy also aims to significantly increase Japanese battery production (Japan NRG 2022), with the domestic battery production capacity set to reach 150 GWh by 2030 (METI 2023d).

In 2023, Japan updated its **National Hydrogen Strategy** (Ministerial Council on Renewable Energy, Hydrogen and Related Issues 2023), aiming to cut carbon emissions in heating, power, and carbon recycling with products like synthetic fuels (ANRE 2022). The strategy targets expanding hydrogen use to 3 million tons by 2030 and 20 million tons by 2050, with an interim goal of 12 million tons, including ammonia, by 2040 (ANRE 2023). Japan plans a 15 GW increase in water electrolyzer capacity to increase hydrogen production for domestic and international use, aiming for hydrogen and ammonia to supply 1% of its energy by 2030 (Ministerial Council on Renewable Energy, Hydrogen and Related Issues 2023).

Unlike in Germany, nuclear energy remains important in Japan's energy mix, targeting 20-22 % of electricity generation by 2030 as it restarts safety-approved reactors (Matsudaira and Minatogawa 2024).

In alignment with the Green Growth Strategy, the IEA (2021) forecasts that by 2050, renewables will meet 50-60 % of Japan's electricity needs, supplemented by nuclear, thermal (with Carbon Capture Utilization and Storage), and 10% from hydrogen (IEA and International Energy Agency 2021).

To advance new energy technologies, renewables, and carbon reduction, Japan established a financing framework under the **Green Transformation (GX) Strategy**, launched in 2023 (Matsudaira and Minatogawa 2024). This strategy plans to mobilize over 150 trillion JPY through public-private investments and "GX-Bonds" within a decade (Cabinet Secretariat 2023).

### 3.2.2 The role of CRMs in Japan’s energy transition technologies

Similar to the German context, a precise estimate of Japans national demand for CRMs for the implementation of the expansion targets for energy transition technologies described above is difficult. However, a few figures can be cited here as examples to illustrate the dimensions of the challenging task of ensuring a secure supply of CRMs for the energy transition.

METI has conducted an analysis on the requirement for **copper** and neodymium to cover the future expansion requirements for wind power: for every MW of **offshore wind** turbine capacity, approximately 11.5 tons of copper and 0.1 ton of neodymium are needed (ANRE 2021b). In contrast, **onshore wind** power generation requires around 1.7 tons of copper and 0.07 ton of neodymium per MW (ANRE 2021b).

Similarly, Japan’s targets for expanding installed **PV** capacity will lead to a notable rise in demand for raw materials like **copper**, silicon, and silver, with alternative technologies having the potential to change the demand for CRMs significantly (IEA and International Energy Agency 2021). In order to reduce its reliance on certain raw materials and decrease the dependence on China for critical PV cell materials, Japan has been intensifying efforts in developing perovskite solar cell technology, which utilize iodine. This would provide Japan leverage due to its status as a major iodine producer and reduce dependence on certain raw material imports (METI n.d.). The Prime Minister of Japan has revealed plans to achieve commercial production of perovskite solar cells by the year 2025 (The Japan News 2023).

In order to achieve the expansion targets for battery production formulated in the Battery Industry Strategy (2022), the Battery Association for Supply Chain (BASC) (2022) estimates an annual demand of approximately 100,000 tons of **lithium**, 90,000 tons of **nickel**, 20,000 tons of **cobalt**, 150,000 tons of graphite and 20,000 tons of manganese.

While no quantitative estimates are available regarding the raw material requirements needed to achieve the targets for the expansion of hydrogen infrastructure set out in the 2023 National Hydrogen Strategy (Ministerial Council on Renewable Energy, Hydrogen and Related Issues 2023) , an overall increase in demand for CRMs needed in **electrolysis**, such as **REE**s, **nickel** and **platinum** (IEA 2022b; DERA 2022c) can also be expected in Japan.

Japan relies heavily on import of CRMs, predominantly from China, a country which dominance extends across the entire supply chain and especially in the mining, separation, purification, and refining phases (DeWit 2021). In 2018, Japans imported 58 % of CRMs from China, followed by Vietnam at 14 %, France at 11 %, Malaysia at 10 %, and the remaining 8 % from various other countries (ANRE 2020). This highlights Japan's significant reliance on a few countries for CRM supply (DeWit 2021). The dependence on imports from China may pose a risk in light of past geopolitical tensions between the copuntries, prompting Japan to seek ways to diversify its supply chains (DeWit 2021) In addition, the overall market consentration of CRMs in a handful of countries, some of which face political instability, further exacerbates supply risks (ANRE 2020). Given that increased access to rare earths is crucial for decarbonizing the domestic economy, Japan finds itself in a competing position with China (DeWit 2021). In addition, competition for CRM resources is expected to intensify among major economies as well as emerging economies (ANRE 2020). This situation highlights the need for Japan to diversify its supply chain for CRMs. By adopting comprehensive strategies and navigating global complexities, Japan aims to enhance resilience and sustainability (DeWit 2021), (ANRE 2020).

Recognizing the critical importance of CRMs for Japan’s industrial and economic growth, the country has strategically focused on diversifying its sources of supply. This diversification extends beyond mere importation and includes investments, processing, and recycling initiatives and the development of alternative materials (see chapter 4.2 for more details) (ESCAP 2023).

### 3.2.3 Policy Framework for securing raw materials supply

The Japanese government's strategy for securing the supply of critical minerals, defined in the **Basic Guidelines for Securing Stable Supplies of Specified Critical Minerals (2004)**, is characterized by a collaborative approach between stakeholders in the public and private sectors, emphasizing predictability and resilience in supply chains. According to these guidelines, the government employs targeted national measures tailored to the specific characteristics of each mineral. These include grants and financial incentives aimed at diversifying supply sources, enhancing production technologies, and encouraging the development of alternative materials to reduce external dependencies. Regular supply chain surveys are conducted, incorporating advances in digital transformation, to adapt strategies to current supply and procurement realities. Minerals are classified as critical based on their necessity for national survival, reliance on external sources, and the impact of potential supply disruptions. This classification is dynamic, with adjustments made in response to global and socio-economic changes. The strategy includes evaluating the risks of supply disruption due to external actions, such as export restrictions or prioritized supply within exporting countries, to preempt potential threats to national and citizen safety (Cabinet Office Governement of Japan 2004).

**Japan's international resource strategy** is geared towards securing a stable supply of these essential minerals (METI 2020b). This strategy involves an assessment of risks associated with each type of resource, focusing on the uneven global distribution of these resources, the stability of the producing countries, and future supply and demand projections. A key element of this strategy is to reinforce the stockpiling system for 34 types of rare metals, ensuring a reserve in times of supply disruptions (IEA 2022a).

**Japan's Policy on Measures to Ensure Stable Supplies of Critical Minerals** aims to mitigate the challenges of high dependency on imports and potential monopolization by certain countries, especially in the context of critical minerals like REEs (METI 2023f). To counter this, the policy focuses on diversifying and fortifying the supply chain through initiatives like supporting resource exploration and development via the Japan Organization for Metals and Energy Security (JOGMEC), and aiding the discovery and development of new mines and refining facilities. The supply chain vulnerabilities are also mentioned in the **Economic Security Promotion Act** (passed in 2022 by Japan’s new Economic Department within its National Security Secretariat) (CISL and Wuppertal Institute 2023). This Act prioritizes economic security over market efficiency and prioritizes reducing Japan’s reliance on China as primary supplier of CRMs.

The strategy **Toward Strengthening the Battery Supply Chain** (BASC 2022) addresses the specific challenge of securing minerals for battery production. It discusses challenges and strategies related to the battery supply chain in Japan, with a focus on securing critical battery metals and enhancing the country's battery manufacturing capabilities (BASC 2022).

Additionally, Japan emphasizes strengthening its bilateral and multilateral cooperation to secure access to CRMs. The United States and Japan recently entered into **Critical Minerals Agreement** focused on the critical minerals sector, with the primary goal of enhancing and diversifying the supply chains for these crucial materials (United States Trade Representative 2023). This new arrangement builds on the foundations set by the 2019 U.S.-Japan Trade Agreement and places a strong emphasis on supporting the evolution and implementation of electric vehicle battery technologies (United States Trade Representative 2023). Key aspects of this agreement include a mutual understanding to avoid imposing export duties on critical minerals and to take domestic actions to counteract non-market-oriented policies that impact the trade of these minerals (United States Trade Representative 2023).

# 4 Circular economy solutions for critical raw materials for the energy transition

As chapter 3 shows, some of the various strategies developed by Germany and Japan to secure the supply of CRMs include similar approaches. One approach centres on increasing the domestic production (extraction and processing) of CRMs, which is not always viable, because not all CRMs can be found locally in Germany and Japan. In addition, the primary production of raw materials is associated with significant negative environmental and social impacts, including high GHG emissions (WWF 2023). This might lead to resistance among communities in regions where, for example, new mining areas are to be developed and conflicts with the achievement of climate policy goals as described in chapter 2.1. Another approach included in several strategies is the diversification of CRM supply chains to avoid disruption. However, by importing larger quantities of CRMs from different sources, consuming countries simply leave the solution of the environmental and social problems associated with primary extraction to other countries (CISL and Wuppertal Institute 2023). In addition to environmental degradation, the development of new mining sites can spark new conflicts over land use and expropriation: according to IRENA (2023), approximately 54 % of minerals critical for the energy transition are found in areas that are on or adjacent to lands inhabited by indigenous peoples. This contradicts the approach of a comprehensive sustainable transformation of the energy sector that involves everyone equally (CISL and Wuppertal Institute 2023). Similarly, stockpiling CRMs is not a sound solution to mitigate supply risks, as it can exacerbate market constraints, drive up global prices for materials in high demand and lead to unequal access to affordable CRMs, which could exclude poorer countries from the energy transition, delaying global climate mitigation action overall (IRENA 2023).

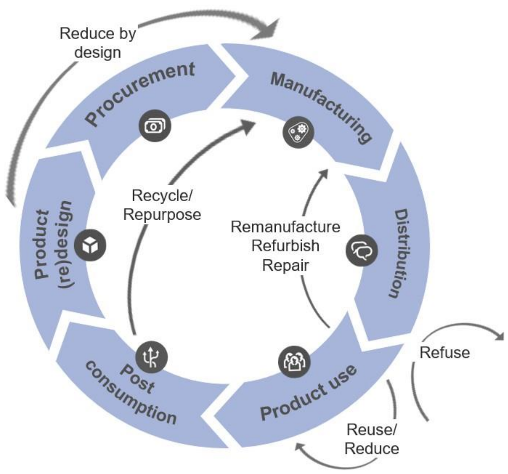
For this reason, some governmental strategies are already focussing on the potential of **CE approaches**. As part of the Communiqué of the G7 Ministers' Meeting on Climate, Energy and Environment in Sapporo in 2023, Japan and Germany, together with France, United States, United Kingdom, Italy and Canada, made a commitment to strengthen supply and circularity along global supply chains of critical minerals and raw materials in order to minimize the environmental and social footprint of energy transition technologies and reduce pressure on primary sources. In the communiqué, the G7 ministers committed to the goal of keeping products containing ciritical minerals and raw materials in the economy for as long as possible and promoting the recovery and recycling of CRMs from electronics, mine tailings, and other matrials in compliance with strict environmental and social standards (MOE 2023).

But what role exactly can the CE play in the energy transition in relation to access to CRMs?

While there is no standardised definition, CE approaches generally aim to avoid or reduce material consumption and waste (Ekins et al. 2019; CISL and Wuppertal Institute 2023). This can be achieved through various methods and approaches that cover the full life-cycle of a product or service, as displayed in Figure 3.

There are different approaches to systematising the various CE approaches (Cf. CISL and Wuppertal Institute 2023; Systemiq 2022; Günther et al. 2019; Fichter et al. 2023), which differ in terms of granularity and complexity. One frequently referenced systematisation, which is also used on the United Nations Environment Programme's (UNEP) Circularity Platform (UNEP 2019), is the **"9-R" concept**, which can be applied in various ways to the key technologies of the energy transition:

**Figure 3: 9-R concept as applied in the circulairty approach**




Source: Own illustration based on information from UNEP 2019.

As a guiding principle, **Reduce by design** (also: Circular Design) implies that already in the design phase of products (and services) such as wind turbines, solar panels, batteries or electrolyzers, their reparability, dismantlability, reusability and recyclability should be taken into account in order to achieve an extended service life and waste avoidance (Günther et al. 2019; UNEP 2019). The mixing of different materials should also be avoided as far as possible in order to enable recycling (without loss of quality) and easier repareability (CISL and Wuppertal Institute 2023). Overall, design decisions can favor the **Reduce** approach, for example if the material efficiency of a product is improved (i.e. less emission-intensive bulk materials such as aluminium are used in energy technologies) or raw materials are substituted, i.e. with less environmentally harmful substances (CISL and Wuppertal Institute 2023; Systemiq 2022; Günther et al. 2019). This is in line with the **Refuse** approach, which aims to ensure that, for example hazardous and toxic materials or components are used as little as possible or not at all in products. For example, efforts are being made to reduce or avoid the use of lead in PV modules (Gebhardt et al. 2022). **Reuse** and **Repurpose** are both approaches aimed at extending the useful life of products (without the need to repair damage), either in their original function or in a new one (UNEP 2019). For example, recovered electric vehicle batteries can be re-used as second-life storage batteries for energy surpluses from wind farms (EC 2023c) or for elertricity storage in homes. If damage occurs during the service life of a product (or service), it can be corrected by **Repair** (e.g. by replacing a defective component). The basic prerequisite for this is that a certain extent of modularity has been incorporated into the design of a products, which allows individual parts and components to be repaired or replaced. **Refurbish** and **Remanufacturing** both address the end of a product's life, when it is by definition already waste. The aim is to restore or improve performance through individual measures or a standardized industrial process, so that a product becomes fully functional and can once again fulfil at least the purpose for which it was originally developed (UNEP 2019). It is estimated that 45 to 65 % of the current global PV waste stream could be avoided by repairing or refurbishing PV modules, however there is currently still a lack of a formalized and systematized processes in many places that would allow for the application of such circular approaches (Tsanakas et al. 2020). Lastly, **Recycle** covers all operations that avoid waste disposal and that aim to close the material loop by returning material to the cycle, e.g. by reprocessing waste into materials (Systemiq 2022; UNEP 2019). For the implementation of recycling, a collection infrastructure is necessary and recycling itself can be done by applying different technologies such as manual work, mechanical work, chemical and metallurgical processes (UNEP 2019). The highly specific requirements for the recycling process and the often complex material composition mean that there are currently still major challenges in recycling some (components of) important energy transition technologies, such as wind turbine blades. Due to a lack of recycling capacity, it is estimated that by 2030 around 570 million tons of wind turbine blade waste will be generated in the EU alone (EC 2023b). Recycling also entails "urban mining", in which materials are recovered from anthropogenic deposits (material stocks of durable goods, infrastructure, buildings and landfills) instead of natural deposits (Günther et al. 2019).[4]

Many of the above-mentioned approaches provide a double contribution to the climate goals of countries; not only can CE approaches secure access to CRMs, which are needed for the expansion of sustainable energy technologies. Replacing primary raw materials with secondary ones can also cuts down GHG emissions, as recovering materials, for example through recycling, is significantly less energy-intensive than mining and transporting primary raw materials (EEA 2024). If, for example, primary aluminium is replaced by secondary material, 95 % of the energy consumption can be saved (CISL and Wuppertal Institute 2023).

Circular approaches also aim at retaining products and materials in use for as long as possible, thus reducing the demand for new primary materials and the GHGs emitted during their extraction and processing (EEA 2024). Simas et al. (2022) estimate that the demand for seven raw materials that are critical for the energy transition (lithium, cobalt, nickel, manganese, rare earth elements, platinum and copper) could be reduced by 18 % between 2022 and 2030 through the application of circular approaches. The report also expects that 20 % of the total mineral demand could be supplied by recycling between 2022 and 2055. In addition, it is projected that by 2050, a significant portion of the minerals necessary for the green transition could be obtained from recycling efforts (Simas et al. 2022). In this way, the promotion of circular approaches contributes to the overall climate policy goal of reducing the carbon footprint of energy transition technologies and thus achieving the Paris climate target.

Some CRMs posess a significant potential for both technical and economically viable recycling, however recycling rates worldwide are generally still low for various reasons and cannot adequately meet the growing demand for CRMs with secondary raw materials. One of the reasons for this is that currently, cost-effective sorting and recycling technologies for many CRMs are not yet developed, and a large portion of CRMs remain in use within long-lifespan infrastructures.(Gislev et al. 2018; IRENA 2023). For example, for wind turbines (currently installed in Europe), Gislev et al. (2018) assume a service life of 30 years. Batteries from electronically powered vehicles, for example, are generally available to the recycling market after 10 to 15 years (possibly even later if refurbishment approaches are used) and PV modules are assumed to have an initial service life of up to 25 years (after which the modules could be used for a

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[4] Another important approach, mentioned by several studies, is that of "Rethinking", which involves redesigning business models and moving from a focus on products to the provision of services (shift from "owning" to "using"). The approach is intended to reduce the demand for new products through systemic changes in the way demand is met, for example in the field of mobility through car sharing services instead of individual car ownership (Systemiq 2022; Günther et al. 2019). Rethinking approaches are not included in this study due to the (so far) limited application possibilities in the energy sector and the expected inevitable construction of new plants in the coming years, but are an important part of a comprehensive transformation towards a CE.

further 10 to 15 years in second life applications at a performance of 80 %) (Fichter et al. 2023).

In order to implement the aforementioned CE approaches, a suitable institutional framework and incentives for companies are needed to make CE solutions possible and viable. This chapter aims to shed light on the current regulatory framework in Japan and Germany on CE approaches (for CRMs) so that, in chapter 5, overlaps and gaps in the approaches can be identified.

## 4.1 Germany

In order to achieve its climate-neutrality objective and the goals of the energy transition, Germany will require large quantities of CRMs in the future. Per capita raw material consumption in Germany is already well above the global average (UBA 2023b). Overall, Germany already has a well-developed and high-quality waste management system and structures for waste collection, sorting and recycling as well as comprehensive product responsibility, which would generally allow for the introduction of CE approaches (BMUV 2023e). For example, a total of over 899,000 metric tons of electrical and electronic equipment was recycled in Germany in 2020, which corresponds to an increase of 11.2 % compared to 2019 (DESTATIS 2022).

According to EUROSTAT, however, the share of secondary raw materials in total raw material consumption in 2022 was only around 13 % (within the EU, this puts Germany at 8th place, with the Netherlands having the highest circular material use rate at 27,5 %) (EUROSTAT 2022). With regard to the recovery and reuse of metals, high rates are achieved in Germany for so-called bulk raw materials (iron/steel, non-ferrous metals) and precious metals (gold, platinum). The recycling rate for steel, for example, is at around 90 % and steel scrap accounts for around 43 % of all input materials in steel production in Germany (BMWK 2020; BGR 2022). Aluminum recycling rates even range from 90 to 95 % depending on the area of application (BMWK 2020) and the share of secondary raw materials in copper production was at approximately 38 % in 2021 (BGR 2022). However, only low rates are realised in the recovery of special metals and some industrial metals, as these materials pose major logistical and technical challenges in the economic organisation of collection, processing, recycling and use of recyclates (BMWK 2020; Kreibe et al. 2020). The BMWK points out that the recovery of special metals such as REEs, indium, gallium, germanium and lithium still poses technical challenges due to complex alloys, which require further advances in processing technology and the implementation of new metallurgical processes (BMWK 2020).

At EU level, recycling already accounts for between 35 and 44 % of the demand for the CRMs vanadium, tungsten and cobalt (based on data from 2015/2017; for other CRMs such as antimony, magnesium and natural graphite, the rates range from 0 to 17 %) (Gislev et al. 2018). However, these rates are not sufficient to reliably cover rising demand in the future.

### 4.1.1 Policy framework for circular approaches for critical minerals

Potential demand bottlenecks, vulnerabilities and negative environmental impacts of a growing primary raw material use as described above have been recognized both in Germany and at the European level, which is why various policy goals, strategies and instruments have been issued in recent years to strengthen circular approaches to meet CRM needs.

In various strategies and laws, the German government has committed itself to overall promotion of CE approaches: Germany's current **National Sustainable Development Strategy** (last updated in December 2020, updated version adopted in March 2021), contains the clear goal of decoupling the demand for raw materials from economic growth via the implementation of CE approaches (The German Federal Government 2021). In accordance with the latest coalition agreement, the German Federal Government has also started working on a **National Circular Economy Strategy** (Nationale Kreislaufwirtschaftsstrategie, **NKWS**) in 2022, which is based on the CE vision as described in the EU 2020 Circular Economy Action Plan (CEAP).[5] The strategy is intended to harmonise all existing goals and approaches for implementing circular approaches and resource efficiency in Germany in order to provide a "framework for the government to define goals, basic principles and strategic measures that support all strategies relevant to raw material policy" (BMUV 2023d). In June 2024, the Federal Environment Ministry (BMUV) published a draft of the NKWS, on which stakeholders from industry, society and science were invited to submit written comments by the beginning of July 2024. Among other things, the proposal stipulates that the annual primary raw material consumption per capita should be reduced to 8 tons by 2045 (for abiotic and biotic primary raw materials combined). The draft emphasizes the need to close material cycles, particularly with regard to CRMs for energy transition technologies, in order to contribute directly to resource and climate protection and at the same time increase the resilience of supply chains for the industry. Against this backdrop, a number of specific measures and instructions are listed to strengthen CE approaches, particularly for critical and strategic metals; for example, the German government wants to support the introduction of

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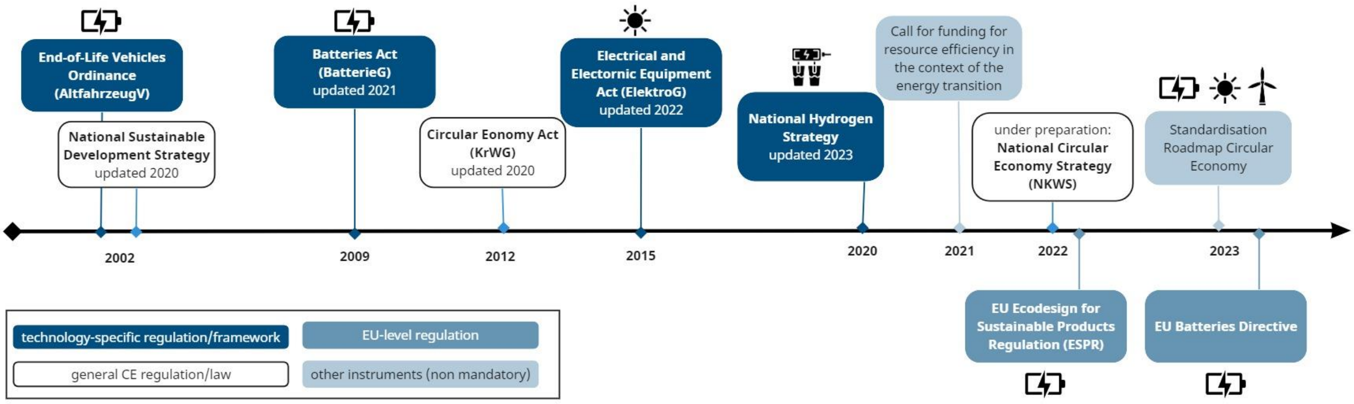
[5] The 2020 CEAP aims to reduce the European industry's dependence on raw material imports and provides for 35 actions to strengthen the CE, including for certain product groups with a particularly high potential for circularity (including batteries and vehicles) (CISL and Wuppertal Institute 2023; EC 2020b). As an action plan, the CEAP does not contain binding requirements for implementation at national level, but encourages all EU member states, including Germany, to implement its objectives and retains the right to use the EC's enforcement powers in future if necessary (EC 2020a).

**Figure 4: Overview of policy frameworks in Germany**




Source: Own illustration.

so-called Digital Product Passports (DPP) at EU level (see more under the “Batteries” section in this chapter), expand and further develop suitable funding programmes, support standardization processes for increased recyclate qualities for metals and introduce separation obligations for strategic metals from commercial waste. In addition, the draft provides for a strengthening of international cooperation in the further development and promotion of the circular economy and resource efficiency to solve global environmental crises and also explicitly addresses the continuation and strengthening of bilateral cooperation with Japan (see Chapter 5 for more on existing cooperation formats) (BMUV 2024).

The primary regulation that currently provides the framework conditions for the promotion of CE approaches in Germany is the **Circular Economy Act (Kreislaufwirtschaftsgesetz, KrWG)**, which was originally adopted in 2012. It contains the basic provisions for handling waste and promotes the prevention, recovery and disposal of waste. In 2020, the **KrWG was updated** to implement the requirements of the amended European Waste Framework Directive (Directive 2008/98/EC on waste, amended by Directive 29018/951/EU). The update aims to strengthen CE approaches, in particular through waste prevention and increased recycling, also with regards to CRMs. The KrWG refers to the EU definition of CRMs and introduces certain restrictions on the use and handling of products containing such CRMs. This means that certain products containing CRMs may only be placed on the market with labelling that specifically indicates the need to return them to the manufacturer, dealer or specified third parties. In addition, the amendment extends the product responsibility requirements to CRMs. Specifically, the amended text states that CRMs should be used sparingly and that all CRMs contained in a product must be clearly labelled in order to prevent the products from becoming waste without the CRMs contained in them being recovered. The amendment also introduced new requirements for **sustainable public procurement** for German federal authorities. Among other things, authorities are obliged to favour products that are "characterised by durability, ease of repair, reusability and recyclability", which can be especially relevant in the context of purchasing electrical appliances that often contain CRMs (BMUV 2020). The requirements for public procurement in the KrWG thus replace the previous guiding obligation to assess whether environmental considerations can be taken into account when making purchasing decisions and awarding contracts (= obligation to assess), which was formulated in the Act against Restraints of Competition (Gesetz gegen Wettbewerbsbeschränkungen, GWB). Instead, the amendment to the KrWG introduces a preference obligation (sustainable products and services must be given preference). The obligation to assess had previously been implemented by a number of mandatory regulations, for example via the Public Procurement Ordinance (Vergabeverordnung, VgV) in the area of vehicle procurement (Vergabeblog.de 2021).

In addition to these overarching regulations for the implementation of CE principles, some of the key strategy papers on securing Germany's future supply of raw materials presented in chapter 3.1.3 contain specific obligations for the implementation of CE approaches. Both the German government's 2020 Raw Materials Strategy and the BMWK's supplementary Eckpunktepapier of 2023 describe the expansion of recycling and the CE as key pillars of Germany's future raw materials supply. With regard to CE approaches for CRMs, the 2020 **Raw Material Strategy** envisages, among other things, that the German government will promote R&D in the field of processing technology and metallurgy in order to optimize complex recycling processes and increase economic efficiency, particularly for raw materials relevant to the future such as REEs, lithium or indium. New business models for extending the use of products and the raw materials they contain and corresponding research projects are also to be promoted. While the formulated goals focus strongly on innovations in the field of recycling, the strategy emphasizes that CE approaches also go beyond this and that the dialogue on possible further circular solutions is supported (BMWK 2020).

The **Eckpunktepapier** published in 2023, which is intended to supplement the Federal Government's raw materials strategy with further measures, continues to focus on "circular economy, resource efficiency and recycling" as one of three key pillars. For example, lead markets are to be established through quotas for recycled raw materials and recyclates, legal hurdles, norms, standards, approval and planning procedures are to be adapted so that recycled materials can be used more effectively and innovation, R&D on resource efficiency and recycling are to be supported through minimum regulatory requirements and financing instruments (BMWK 2022a). While the regulations and instruments mentioned so far do not contain any specific requirements for individual energy technologies and the CRMs they contain, such requirements for PV systems, wind turbines, battery/storage systems and electrolyzers already exist to some extent in the German policy context.

### Batteries

Among all energy transition technologies covered by this study, Germany has adopted the largest number of policy instruments that actively promote the implementation of CE approaches for batteries: The **Batteries Act** (Batteriegesetz, BatterieG), which transposes the European Battery Directive 2006/66/EC into German law, first came into force in 2009 and was updated in 2021 (BMUV 2021). The Battery Act regulates the placement on the market, take-back and environmentally sound disposal of batteries in Germany. All types of batteries are covered, i.e. both rechargeable batteries (accumulators) and non-rechargeable batteries. All manufacturers who place such batteries on the German market commercially have to be officially registered, participate in take-back systems and fulfil certain labelling obligations. All retailers (including online retailers) must take back all batteries they sell free of charge from consumers after use and hand over the waste portable batteries to the manufacturers for recycling or disposal (IHK Köln n.d.). With the 2021 update, various changes were introduced that favour the recycling of batteries and the recovery of CRMs they contain. For example, the update increased the minimum collection rate that take-back systems must achieve annually from 45 % to 50 %. In addition, battery manufacturers are obliged to increase the durability, reusability and recyclability of portable batteries (UBA 2020a).

As another key product group for the recovery of CRMs, the disposal of batteries from electric vehicles is regulated by the **End-of-Life Vehicles Ordinance** (Altfahrzeug-Verordnung, AltfahrzeugV). The automotive sector consumes about half of the total EU consumption of some CRMs, but currently some of these, such as REEs in electric traction motors or palladium in embedded electronics, are not recovered after shredding (BVSE 2023). The AltfahrzeugV provides rules for an environmentally sound disposal of end-of-life vehicles in Germany and has been in force since 2002. The AltfahrzeugV obliges vehicle manufacturers to take back all end-of-life vehicles of their brand and to create comprehensive return options. In addition, the AltfahrzeugV stipulates that from 2015, manufacturers, commercial importers, distributors, the end-of-life vehicle disposal industry and motor vehicle insurance companies must jointly ensure that at least 95 % of the average empty weight of an end-of-life vehicle is recycled. Up to and including 2021, this target was achieved every year with the exception of 2019 (BMUV 2023a). When disposing of electric vehicles, both the AltfahrzeugV and the BatterieV apply. Accordingly, vehicle batteries may not be incinerated or disposed of in landfill, but must be removed and recycled (Sonderabfallwissen 2020).

As another important framework strategy for the future development of the battery industry in Germany, the **BMBF's “umbrella concept” for battery research** aims to strengthen the research fields of recycling and the CE and formulates clear goals, including that by 2030 the number of companies involved in battery recycling should be over 40 and at least 90 % by weight of materials from end-of-life batteries at the cell level should be recycled back into the production of battery cell (BMBF 2023a). In addition, the BMUV supported the development of a **Standardisation Roadmap Circular Economy**, which was drawn up jointly by experts from industry, academia, the public sector and civil society and published in January 2023. The roadmap makes proposals on which standards and specifications need to be adapted and which new standards need to be developed in order to implement CE approaches in seven thematic areas (digitalisation, business models and management, electronics and ICT, batteries, packaging, plastics, textiles, consumption and municipalities) (BMUV 2023c).

In addition, to the existing German regulations, two recently adopted European legislations introduce new requirements for the recycling and circularity of batteries, which will have a significant impact on securing CRMs from batteries in Germany. The new **EU Batteries Directive**, which came into force in August 2023, is the first European legislation to adopt a "full life-cycle approach in which sourcing, manufacturing, use and recycling are re addressed and enshrined in a single law" (EC 2023d), in line with the targets of the 2020 EU CEAP. From 2025 onwards, targets for i.e. efficient recycling, recovery of materials, and recycled content will be introduced. In particular, high recycling rates must be achieved for CRMs such as cobalt, lithium and nickel (through collection and more strict targets for recycling efficiency and material recovery). The directive also prescribes mandatory minimum levels of recycled content, which are initially set at 16 % for cobalt, 85 % for lead and 6 % for respectively for lithium and nickel. The Batteries Directive also introduces a Digital Product Passport (DPP), which is intended to provide detailed information on the composition of the battery via a QR code and thus facilitate recycling management. The law now is to be applied in the Member States, including Germany. To this end, the EC will prepare further secondary legislation (implementing and delegated acts) with more detailed provisions (EC 2023d). Likewise, the updated **Ecodesign for Sustainable Products Regulation (ESPR)**, which came into force on July 18, 2024 as Regulation (EU) 2024/1781 and thus replaces the old Ecodesign Directive, mentions the introduction of a DPP as a key tool to enable the traceability of products and their components. The DPP is intended to create the legal basis for introducing binding requirements, such as the recyclability of products and possible bans on products that do not allow the CRMs they contain to be recycled. The ESPR contains further requirements for product design and the provision of information to improve the reparability, durability and recyclability of products (CISL and Wuppertal Institute 2023; EC 2022). Overall, the ESPR does not determine specific measures, but rather creates a framework for their subsequent implementation. The requirements for certain products or product groups will be defined in a second phase by several delegated acts, which are expected to be developed and adopted between 2024 and 2027. The delegated acts are to be drafted in close consultation with the Member States and a group of experts and stakeholders in the so-called "Ecodesign Forum" (Boewe and Rasche 2024; European Parliament and Council of the EU 2024b).

**PV/solar panels**

For PV/solar systems, the number of policy instruments that promote CE approaches for CRM recovery to date are significantly lower than those providing incentives for batteries: The **Electrical and Electronic Equipment Act** (Elektro- und Elektronikgerätegesetz, ElektroG) first entered into force in 2015 and was last amended in 2022. It transposes the European Directive on Waste from Electrical and Electronic Equipment (WEEE Directive 2012/19/EU) into German law (BMUV 2022). It is intended to implement waste product responsibility for manufacturers of electrical and electronic equipment, which also entails solar modules, by ensuring the proper collection and return of old appliances and reducing the amount of waste through reuse, preparation for reuse or recycling, among other things. With the 2022 amendment, the obligations of manufacturers were comprehensively extended to cover the entire life cycle of such devices. The ElektroG also stipulates that all manufacturers of electrical and electronic equipment must register before placing their products on the German market. In addition, consumers are obliged to dispose of old appliances separately from household waste. Old appliances from private households can be handed in free of charge at collection points run by public waste disposal organisations, where some of them are collected by the manufacturers for professional disposal. The amendment also obliges retailers with a certain sales area that offer electrical appliances to set up free take-back collection points. All properly collected waste appliances must be tested in certified primary treatment facilities to determine whether the entire appliance or individual components can be reused or recycled. In addition, certain recycling quotas must be achieved during final disposal (UBA 2021): Since 2019, at least 65 % of electrical and electronic appliances placed on the German market in the last three years (measured by total weight) are to be collected via take-back systems. In 2021, however, this target was clearly missed with a collection rate of only 38.6 %. The ElektroG also stipulates that between 55 and 80 % of the waste appliances collected each year must be prepared for reuse or recycled, depending on the appliance category. These quotas were met in all six appliance categories in 2021 (UBA 2023a). The 2021 update also introduced new rules specifically regarding recycling of old PV modules. For example, silicon-based and other modules must be treated separately and certain limit values for lead, selenium and cadmium, for example, must not be exceeded (energie-experten.org 2022).

**Other technologies: Wind power & hydrogen/electrolyzers**

The research team is not aware of any comparable nationwide guidelines or policy instruments that promote the implementation of CE approaches for **wind** turbines. The disposal of waste resulting from the dismantling of wind turbines in Germany is regulated by the KrWG. However, the dismantling process itself is subject to various regulations set by different federal states (Otto et al. 2023). Additionally, the German Federal Immission Control Act (Bundesimmissionsschutzgesetz, BImSchG) mandates that operators are responsible for the dismantling and recycling of their turbines. This means that each operator must develop individual dismantling and recycling plans to meet the specific technical requirements of the diverse range of turbines and locations (UBA 2020b). This diversity complicates the establishment of a uniform and general approach to the end-of-life (EOL) management of wind turbines. A 2023 study commissioned by the Federal Environment Agency (UBA) on the development of good practice measures for the dismantling and recycling of wind turbines also describes that there is usually little or no relevant manufacturer information available at the time of dismantling that would allow for efficient recycling. As a result, there are also no general specifications for the recycling of CRMs from wind turbines (Otto et al. 2023).

Similarly, no specific requirements for **electrolysis** stacks were identified that would demand or promote the introduction of CE approaches. However, the updated German government's National Hydrogen Strategy formulates the goal of promoting basic research into energy materials in order to significantly reduce the consumption of CRMs for hydrogen production or to substitute these raw materials (BMWK 2023a).

### 4.1.2 Coordination bodies, engagement in multilateral formats and international cooperation

In Germany, issues relating to the supply of CRMs are mainly dealt with by the **BMWK**. The German Raw Materials Agency (**DERA**) was founded in 2010 as part of the implementation of the first Raw Material Strategy in order to support the ministry's work on these key issues. DERA forms part of the Federal Institute for Geosciences and Natural Resources (**BGR**), a technical-scientific higher authority within the BMWK's portfolio. DERA is responsible for monitoring price developments, supply and demand trends for mineral raw materials and selected intermediate products. This information is intended to help German companies to identify potential price and supply risks as well as critical developments on the markets at an early stage and to develop suitable alternative strategies. In addition, there is R&D funding for projects on raw material processing and lightweight construction, as well as a new dialogue process with businesses, representatives from scientific institutions and the administration (Presse- und Informationsamt der Bundesregierung 2023). In addition, the **German Resource Research Institute (GERRI)** supports the implementation of the German Raw Materials Strategy. GERRI is supervised by the Federal Insitute for Geoscience and Natural Resources (BGR) and is made up of eight research institutes that advise the German government (BGR 2020).

The transformation towards a CE is a cross-cutting issue that is being addressed by various actors in Germany, with the relevant ministries within the federal government regularly coordinating their efforts. To this end, a **cross-departmental transformation team on the topic of the CE** was set up as part of the German Sustainability Strategy, for which the Federal Chancellery is responsible. The preparation of the NKWS is also accompanied by a stakeholder process, which includes a dialogue forum with representatives of German umbrella organisations under the leadership of the **BMUV**, among others (BMUV 2023b).

In 2015, the German Federal Government initiated the **G7 Alliance for Resource Efficiency** as an international forum for political decision-makers, companies and researchers to promote regional and global resource efficiency (G7 Alliance on Resource Efficiency n.d.). At the 2017 G20 Summit in Hamburg, Germany, the **G20 Resource Efficiency Dialogue** was established, which also promotes the sustainable use of natural resources and has held regular meetings since then (IGES n.d.).

In addition, the Federal Government supports the activities of the EC and is involved in various committees and working groups at EU level. Among other things, the BMWK is a member of the **Raw Materials Supply Group**, where experts from EU member states, industry, research and the civil sector advise the EC on the sustainable supply of raw materials (BMWi 2019). As part of the multi-stakeholder initiative **European Innovative Partnership (EIP) on raw materials**, industry representatives, public sector officials, academics, and NGO members also provide guidance to the EC, EU member states, and private stakeholders on innovative strategies to address challenges associated with raw materials. (EC n.d.b). In addition, **EIT RawMaterials** was founded in 2015 as an innovation community within the European Institute of Innovation and Technology (EIT) to support the sustainable supply of raw materials for the EU. EIT RawMaterials brings together over 300 partners from industry, academia, research and investment and is also intended to support Europe's transformation to a CE (EIT RawMaterials 2023a). EIT RawMaterials leads the **European Raw Materials Alliance (ERMA)**, which was founded in 2020 as part of the EU CRMA. In the initiative, industrial actors along the value chain, Member States and regions, trade unions, civil society, research and technology organisations, investors and NGOs are working together to resolve regulatory bottlenecks and provide investment to strengthen circularity approaches for access to CRMs in the EU, among other things (EIT RawMaterials 2023b).

### 4.1.3 Industry best practices for circular economy solutions for CRMs for energy transition technologies

A number of German companies are already successfully applying some of the CE strategies described in chapter 4 to keep CRMs for the energy transition in the loop (Fichter et al. 2023). The info boxes below present some examples of selected best practices. The selection aims to cover as many different energy transition technologies and CE approaches as possible, but is not comprehensive.

**Refurbish & Repurpose: Used traction batteries as stationary power storage units – Voltfang GmbH**

Old lithium-ion traction batteries can be used in their second life as stationary power storage units, which are used to, for example, supply primary control power to electricity grid operators or for self-power optimisation, load management and peak load capping in the private, commercial and industrial sectors. As the availability of end-of-life vehicles from the electric vehicle market is still limited (due to the only recent uptake in electrical vehicle sales/production), most second-life batteries have so far mainly come from test fleets or are B-goods that have accumulated during the production of new battery modules, because they did not meet the technical requirements of the car manufacturers. In the future, however, the availability of used batteries is expected to increase overall with the expansion of e-mobility (Fichter et al. 2023).

Founded in Aachen in 2021, the start-up company **Voltfang GmbH** is the leading provider of stationary second-life batteries for industrial and business customers in Germany. Voltfang buys used battery modules that still have a capacity of at least 80 %, tests them and determines the available service life.
The second-life batteries are then refursbished and offered to customers within a 10-year flat rate system. If battery modules fall below a critical minimum performance value within this period, they are replaced by Voltfang. To date, Voltfang has primarily offered its second-life batteries as stationary storage systems to companies with a wide network of branches. In the future, however, the company also wants to expand into the field of grid-connected battery storage systems in order to establish a virtual power plant that integrates decentralized energy generation and consumption units. By November 2023, Voltfang had saved 600 high-performance battery modules from premature recycling by refurbishing and reusing them (Fichter et al. 2023).

**Reuse: Second Life usage of photovoltaic modules – 2nd Life Solar GmbH & Co. KG**

In Germany, the recycling of PV modules has so far been carried out in rather informal structures, dominated by independent private companies that do not co-operate with the original manufacturers of the modules. Similarly, the second life market for solar modules is still small, because many consumers lack confidence in the performance of refurbished and used solar modules, there are no standardised reliability tests and the design often does not take sufficient account of dismantlability. However, the waste stream of solar modules will grow strongly in the coming years, with up to one million metric tons of old modules expected to accumulate annually by 2030 alone, meaning that the recycling and reuse infrastructure will have to expand accordingly (Fichter et al. 2023).

The company **2nd Life Solar GmbH & Co. KG**, which was founded in 2023 in Hamburg as part of the family-run waste disposal and environmental services provider Buhck Group, is the first German waste disposal company to focus intensively on the reuse of PV modules. 2nd Life Solar buys used solar modules primarily from large solar parks, which generally replace their modules after 10-12 years in order to keep pace with technological developments. Another important source are PV modules with production defects that are sorted out right after production during quality checks. Old modules from recycling depots however often cannot be refurbished due to broken glass. 2nd Life carries out an extensive quality check on the performance level and sells modules that still prove to be efficient in cooperation with wholesalers, installation companies or non-profit organizations at a price that is often 30 to 50 % below that of new modules. By November 2023, 2nd Life was able to test 120,000 modules per year at its Hamburg site alone. However, the approach also has its limits: due to the costly set-up of the process, performance level testing is only worthwhile for large quantities of identical modules; testing many individual modules from private households is not yet economically viable. 2nd Life is also cooperating with the German Association for Electrical, Electronic & Information Technologies (VDE) on the development of standards for the recycling and reuse of PV modules, in order to establish standardised guidelines for ensuring quality and sustainability of second life modules (Fichter et al. 2023).

**Recycle: Recovery of platinum from fuel cell and electrolysis stacks – Robert Bosch GmbH**

Electrolyzers and fuel cells contain, amongst other things, platinum group metals (DERA 2022c), which have a very high technological and economic recyclability. At 95 %, for example, almost all of the platinum can be recovered from fuel cell stacks. Demand for the valuable metals is also high; according to Marscheider-Weidemann (2021), global demand for platinum could increase by 20 % by 2040 compared to 2018 production levels.

The German company **Robert Bosch GmbH**, founded in 1886 and based in Stuttgart, produces a wide range of mobility solutions, industrial technology, consumer goods, and energy and building technology, also including fuel cell stacks. In September 2023, Bosch signed a contract with mobility provider Hylane, which rents out hydrogen-based trucks, to arrange the return of fuel cell stacks at the end of their life. The contract model guarantees Bosch a buy-back option for the stacks for mobile applications and could, in the longer term, also be applied to the end-of-life handling of electrolysis stacks. Bosch plans to have the stacks recycled by a third-party provider after the buyback. The recovered platinum will then be used by Bosch in the production of new stacks. Bosch has also invested in R&D in order to monitor the service life and functionality of future electrolysis stacks and fuel cells during operation, i.e. by means of digital twins (Robert Bosch GmbH 2023).

## 4.2 Japan

Similarly, to Germany, Japan will require large quantities of CRMs in the future in order to achieve its national decarbonisation targets. Securing access to various CRMs have been an early priority for Japan and this aspect is highlighted in several policy documents. Japan has a realtively high recycling rate of metals, where it recycles 98 % of its metal waste (Benton and Hazell 2015).

When it comes to recycling of e-scrap[6], Japan is one of the top OECD countries, recycling both domestic e-scrap as well as imported. In 2020, 340,000 tons of scrap was recycled in Japan, which corresponds to a reduction of approximately 8 % compared to 2019. In addition, several companies in Japan have built technologies for recovery of different metals, among them copper and nickel (Yoshida 1/25/2024).

JOGMEC provides data on the recycling of different minerals, including nickel, cobalt, and copper, highlighting the amount and rate of recycling - the proportion of waste generated that is successfully recycled (JOGMEC 2024). In 2020, the recycling rates for these minerals stood at approximately 1 %, 0.5 %, and 42 % respectively (JOGMEC 2024).

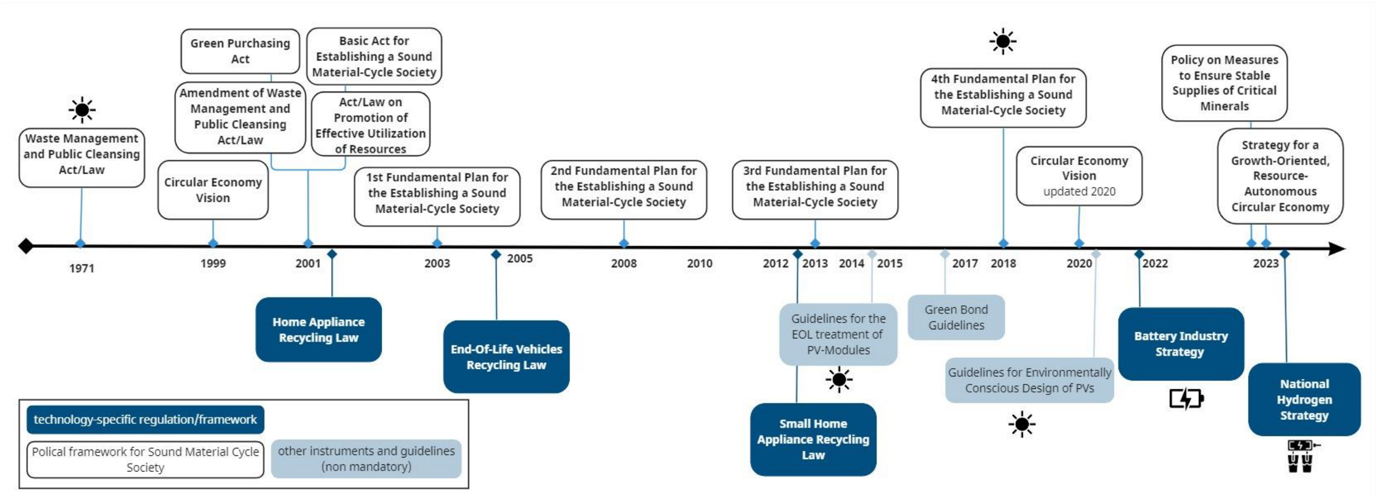
Additionally, statistics on other materials like lithium, nickel, and copper, including their recovery rates, are made available through Material Flow Analysis by the Mitsubishi UFJ Ginkō (MUFG) bank (MFUG 2023). The 2023 data from MUFG reveals that the total amount of lithium found in generated process waste and used products was estimated to be 838 tons (net). For nickel, out of the 73,000 tons recovered from used products, about half (30 kt) was redirected into the production of special steel, with 10,000 tons estimated for reclamation and the remainder utilized in various othermaterials. Furthermore, 15,000 tons was mixed into ordinary steel electric furnaces or used in production of other materials. In the case of copper, the MFA indicated that out of 1,174,000 tons of recovered copper, 182,000 tons was recycled and utilized as electrolytic copper, while the remaining was used as input for the production of products in industries such as automobiles, electric machinery, and others (MFUG 2023).

### 4.2.1 Policy framework circular economy approach for critical minerals

Japan has rolled out policies, strategies, and measures aimed at enabling CE approaches methods to meet the demand for CRMs. According to Benton and Hazell (2015) several factors have contributed to Japan's early adoption of the CE, which include its high population density and limited landfill space, the lack of domestic metal and mineral resources, and a business culture that emphasizes collaboration. This has led to a comprehensive and consumer-friendly approach to recycling, where consumers play an active role in the process, and recycling infrastructure is jointly owned and operated by consortia of manufacturers, benefiting from the recovery of materials and parts. Furthermore, Japan's focus on developing electronics that are easier to disassemble and recycle, avoiding the mixing of different materials, showcases the countries commitment to a sustainable CE (Benton and Hazell 2015).

[6] E-scrap or e-waste or electronic waste can include different metals like copper, gold, platinum and rare earths.

**Figure 5: Overview of policy frameworks in Japan**




Source: Own illustration.

The first major political CE related strategy paper **Act on Promotion of Use of Recyclable Resources** was launched as early as 1991 (Cabinet Secretariat 2002). This paper targeted the recycling (1R) of different products as well as covered design for environment topics for dproducts several products, including vehicles. In 1999 the **Circular Economy Vision** was published by the METI (Tanaka 6/15/2023). The vision marks the transition to the promotion of the 3Rs: reduce, reuse, recycle and included goals to reduce waste generation, improvement of recycling rates, the expansion of environment-related businesses and also the including of more EPR systems for products. The formulation of this vision has led to a consistent reduction in waste generation and significant improvements in recycling rates, supported by recycling laws (Ministry of Economy, Trade and Industry of Japan 2020). Key aspects of Japan's CE approach include a strong emphasis on recycling initiatives, advancements in energy conversion technologies, economic development, and creative innovations (Utrecht University 2023). The Vision was translated into the **Basic Act for Establishing a Sound Material-Cycle Society in 2001** (Wuppertal Institute 2007), aligning with their broader environmental and economic strategies (Arai et al. 2023). This concept aimed to transition from the traditional linear economic model to a more sustainable, and circular one. This was achieved by effectively implementing the three core principles of **reducing, reusing, and recycling, coupled with environmentally responsible waste management practices** (MOE 2014a). Furthermore, the strategies´ goal was to reduce GHG emissions by minimizing incineration and landfilling of carbon-containing substances. It also focused on decreasing energy consumption in production, increasing biomass use, and shifting to renewable energy in processing. In addition, in year 2001, the **Resource Effective Utilization Promotion Act** was published which targets the creation of a sustainable material-cycle economy (MOE 2001) and signifies a step forward from the 1R approach to 3R approach. This is achieved through enhanced recycling by businesses, promoting product longevity and resource efficiency, and reusing components from discarded items. This policy integrates the 3Rs throughout the product lifecycle, from design to waste management. The **Circular Economy Vision,** which was updated **in 2020,** emphasizes a more integrated approach, blending environmental considerations into the economic system (METI 2020a). It advocates for industries to voluntarily incorporate CE practices into their corporate and business strategies, aiming to extend the reach of circular products and businesses to the global market (Nagasaki 2024). In addition, the vision underscores the importance of re-establishing a resilient circular system, designed to endure and thrive in both the mid and long-term perspectives (Nagasaki 2024). Later in March 2023, METI introduced the "**Strategy for a Growth-Oriented, Resource-Autonomous Circular Economy**" to advance innovation in technology and regulations, which aims to establish a self-reliant domestic resource circulation system (METI 2023c). The strategy strives to deepen the 4R (Reduce, Reuse, Recycle, Renewable) policy and strengthen the overseas cooperation. Business-wise it offers CE investment support, as well as digitalization, standardization and start-up venture support. It is also committed to CE partnerships between the industry, the government and academia (METI 2023c). **The MOE's Fourth Fundamental Plan for the Establishment of a Sound Material-Cycle Society,** approved by the cabinet in 2018, focuses on achieving comprehensive resource circulation across all stages of a product's lifecycle (MOE 2018). There is an established reporting process, where the government has to submit annual reports, has to clarify the policies it will adopt to achieve the goals of the act and has to review the Plan for Establishing a Sound Material-Cycle Society every five years. Following Japans 4$^{th}$ Fundamental Plan for Establishing a Sound Material-Cycle Society, the resource productivity rose about up 58 % between the years 2000 and 2015 and the final disposal amount shrunk by 74 % due to the efforts of reducing, reusing and recycling (MOE 2018).

In addition to the overarching strategies, visions and policis, Japan has set policies which target the CE of specific product groups. For example, **Japan's Home Appliance Recycling Act**, implemented in 2001, mandates manufacturers and retailers to recycle household appliances, resulting in high recovery and reuse rates of materials. In addition, the **End-of-Life Vehicle Recycling Act**, enacted in 2005, promotes initiatives to enhance circularity in automobile industry through MFAs, recycling advancements and the promption of material recycling (Yoshida 1/25/2024).

Similarly, to Germany, Japan has legislation for green public procurement. **The Act on Promoting Green Purchasing** was enforced in **2001**, however green purchasing practices go back until late 1980s. Solar Panels are included among the list of designated procurement items in the frame of this GPP policy as of 2016 (MOE 2016).

Japan's long-standing role as a major manufacturer of high-tech, mineral-intensive goods has necessitated a strategic approach to managing critical mineral resources (IEA and International Energy Agency 2021). Since the 1980s, Japan has been proactive in identifying critical mineral vulnerabilities, leading to a strategy focused on designating critical minerals, managing supply risks, and investing in overseas projects, advanced recycling, substitution, and stockpiling resources (IEA and International Energy Agency 2021). The countries expertise in recycling and substitution (as seen oin the case of peroskvite SPVs) is internationally recognized (Benton and Hazell 2015). Advanced recycling is a major priority, with efforts to expand the collection of recyclable materials both domestically and internationally. There is specific focus is on critical minerals like tungsten, cobalt, and select rare earths (Benton and Hazell 2015). For example, the **Policy on Measures to Ensure Stable Supplies of Critical Minerals (2023)** targets, among other things, advancing recycling technologies to reduce reliance on raw minerals (METI 2023f).

**The 6th Energy Plan of Japan (2021)** emphasizes the critical importance of securing a stable supply of mineral resources, such as copper and other CRMs, which are vital for the manufacturing of batteries, semiconductors, and motors (METI 2023f). The plan acknowledges the necessity of mitigating risks associated with the supply of these resources from overseas sources, and highlights the importance of promoting resource recycling from used products to alleviate dependency on external supplies. However, the plan does not set uniform targets for securing overall REs; instead, it focuses on ensuring the supply for each specific type of ore.

### Batteries

In addition to the **Battery Industry Strategy**, Japan has developed a roadmap **Toward Strengthening the Battery Supply Chain** (BASC 2022) which includes the importance of stable CRM procurement, and mentions investments in recycling technology to support the growing demand for battery metals essential for electric vehicles and other applications.

By 2035, the country aims for all new passenger vehicle sales to be electrified (METI 2022c). However, specific policy for recycling of EVs have not been yet established. Japan has an End-of-Life Vehicle Recycling Act, however the necessity for a reliable disposal system for used lithium-ion car batteries was highlighted by a combined working group of the Automobile Recycling Law Council in 2015. Following this, the Japan Automobile Manufacturers Association, Inc. (JAMA) endorsed the creation of a recycling and collection network. A collection system was initiated in October 2018, overseen by the Japan Auto Recycling Partnership, to facilitate this. Currently, these batteries are treated as specially controlled industrial waste. However, with only 12 companies in Japan capable of processing automotive lithium-ion batteries, there are concerns that the existing infrastructure may not be adequate to handle the anticipated increase in battery disposal needs (Yano Research Institute Co., Ltd. 2022).

The topics of reuse, recycling, and repair of **batteries** are currently under discussion by METI's "Study Group on Sustainability of Storage Batteries" (METI 2022b). This group is actively exploring policy goals and strategies to enhance the sustainability of storage batteries used in vehicles. A key focus of these discussions is the development goals outlined by the Green Innovation Fund Project for next-generation storage batteries. An integral part of this initiative is the advancement of storage battery recycling technology. The targeted aim of this technology is to achieve low-cost, high-quality recovery of rare metals, a crucial aspect for the sustainable use of these resources. Specifically, the development goals include achieving a recovery rate of 70 % for lithium, 95 % for nickel, and 95 % for cobalt (NEDO n.d.).

### PV/solar panels

Japan, similarly to other countries utilizing solar panels, faces the challenge of handling the eventual disposal of solar panels, which are expected to generate significant industrial waste in the coming decades. It is estimated that the amount of PV panel waste should peak between years 2035 - 2037 with up to 280 thousand metric tons of disposed panels per year (Bangert 2020).

In 2015, the METI and MOE **published a report on reuse, recycling, and proper disposal of PV-equipment.** which includes a roadmap with a set of activities between 2015 – 2023 which cover, among others, the following aspects: (1) Improvement and establishment of collection, proper disposal, and recycling, (2) Support for technology development, (3) Promotion of eco-friendly design, (4) Guidelines for removal, transport, and disposal of PVs (MOE 2014b). This roadmap established the basis for later developed guidelines for the Promotion of Recycling of PV-Equipment which was published in 2016 and later updated in 2018. Japan does not have laws specifically tailored to PV waste management (Kobayashi 2023). End-of-life (EOL) PV modules are currently governed under the **Waste Management and Public Cleaning Act,** categorizing them as either industrial or general waste. The aforementioned guidelines addressed this gap in 2018. A second edition of guidelines aimed at facilitating the proper end-of-life management of PV systems (Kobayashi 2023). These guidelines are a step towards ensuring environmentally sound disposal and recycling practices for PV modules, aligning with the broader goals of sustainable energy and waste management. Since 2022, Japan's FIT (feed-in-tariff) scheme requires a levy to fund the waste management of EOL PV in advance. Owners of PV systems and plants, excluding residential PV systems (less than 10 kW), are obliged to comply (IEA PVPS 2022). In addition, for PVs the Japan Photovoltaic Energy Association (JPEA) issued in 2016 **Guidelines for Assessment of Environmentally Conscious Design of PV-Modules** in 2016, and in 2020, the MOE issued **Guidelines for Environmentally Conscious Design of PVs**.

**Other technologies: Wind power & hydrogen/electrolyzers**

In 2023 METI and MOE started the **Study Group on the Disposal and Recycling of Renewable Energy Power Generation Facilities**. This Study Group held several key meetings to address the sector's challenges with the first meeting focusing on the overall state and issues of disposing and recycling renewable energy facilities. During the second meeting conversation shifted to solar energy, with the JPEA discussing the proper disposal and recycling of solar panels, highlighting the specifics of solar panel lifecycle management. The later meetings focused on wind energy, led by the Japan Wind Power Association (JWPA) and the Japan Small Wind Turbine Association (JSWTA), discussing disposal and recycling strategies for wind power generation equipment, including small wind turbines. These meetings throughout 2023 underscored a concerted effort to establish sustainable practices for the end-of-life management of renewable energy facilities, crucial for the sector's environmental sustainability and resource efficiency.

The future plans of the Study Group on the Disposal and Recycling of Renewable Energy Power Generation Facilities cover targeted strategies for photovoltaics and wind power generation (METI 2023e). For photovoltaics, the Group is considering an update to the Renewable Energy Special Measures Law to include provisions for disclosing information about substances contained in solar panels. This step aims to enhance transparency and safety in PV materials usage. Additionally, there is a focus on institutional support to encourage safe delivery and recycling of used PV panels, particularly after businesses discontinue operations. This effort might lead to the introduction of a mandatory recycling system, ensuring responsible end-of-life management for solar panels.

Regarding **wind power** generation, future plans of the Group are two-fold. Firstly, there is an emphasis on staying informed of the latest recycling technology developments for large wind turbine blades, which are expected to be introduced in the future. The Group plans to assess and implement necessary measures based on these technological advancements. Secondly, for small wind turbines, they aim to examine and establish appropriate disposal measures, considering the actual industry status and disposal practices. This approach is designed to ensure that both large-scale and smaller-scale wind power installations are managed sustainably throughout their lifecycle. These future initiatives reflect a proactive and comprehensive strategy by the Group to address the sustainable management of various renewable energy technologies.

The **National Hydrogen Strategy** (2023) recognizes the need to establish policy measures for recycling of RE and rare metals which are required for water electrolysis equipment and construction of fuel cells (Ministerial Council on Renewable Energy, Hydrogen and Related Issues 2023). In addition, the development of innovative technologies which would reduce rare metal consumption is mentioned.

For financing, in 2017 the MOE launched the **Green Bond Guidelines** to mobilise private investments into green projects. The guidelines explicitly mention **renewable energy and CE projects**. The scope has been expended in an update of 2020, since then it also covers green loans (MOE 2017).

In 2021, METI and MOE jointly compiled the **Disclosure and Engagement Guidance to Accelerate Sustainable Finance for a Circular Economy.** Companies at the forefront of technological innovation and financial institutions that allocate and manage capital are crucial in driving the shift towards a circular economy. Following directives from the Japanese government, this guidance aims to foster meaningful conversations between businesses and investors, focusing on disclosures and engagements that specifically advance CE objectives. (MOE 2017).

### 4.2.2 Coordination bodies, engagement in multilateral formats and international cooperation

The Sound Material-Cycle Society (SMCS) initiative, spearheaded by Japan's **Ministry of the Environment (MOE)**, is dedicated to addressing pressing socio-environmental challenges both within Japan and globally. This strategy adopts a holistic framework, integrating the three foundational pillars of sustainability—environmental, economic, and social—to ensure comprehensive and balanced progress (see chapter 4.2.1). The MOE is focused on building international collaborations to address societal challenges associated with the CE. The SMCS plan aims to include the participation of citizens, local governments, NGOs, and the private sector (Arai et al. 2023). To this end, MOE is promoting several specific projects, such as a demonstration project for the early social implementation of a decarbonized metal recycling system (MOE 2020a), or a demonstration project for the establishment of a recycling system for plastics and other resources to support a decarbonized society (MOE 2020b)

**Ministry of Economy and Trade and Industry (METI)** is the second major coordinating body for CE solutions. METI published the Circular Economy Vision 2020 to emphasize the need for Japan's transition to a CE. The EU policies on CE had a significant impact on the development of the Japanese CE Vision 2020 (Arai et al. 2023). The METI states that implementing a CE enhance the competitive edge of Japan's industries while fostering a mutually beneficial relationship between environmental conservation and economic development (METI 2020a). The measures proposed by METI include improving resource efficiency, transitioning to highly circular business models, and encouraging companies to engage in voluntary CE initiatives - all with limited regulatory intervention (Arai et al. 2023). In the strategy for a growth-oriented, resource-independent economy (see 4.2.1), METI states that it will provide policy support to the private sector in the areas of CE investment, digitalization, standardization and support for start-ups (METI 2023c).

The interpretation of CE by **METI** differs from the SMCS concept introduced by the MOE. METI's strategy for CE places significant emphasis on economic considerations and involves a broad range of participants and value chains (METI 2020a). CE is seen "a virtuous cycle of environment and growth" (METI 2020a, p. 4). This differs from the SMCS discourse of the MOE, which places greater emphasis on ecological and also social dimensions (Arai et al. 2023) (MOE 2018). However, both the MOE and METI have stated that the two concepts should be promoted in parallel, as they share the same goal: circularity (Arai et al. 2023). **METI** established a 2 trillion JPY Green Innovation Fund as part of the New Energy and Industrial Technology Development Organization (NEDO) (METI 2023b). NEDO is a national R&D agency that accelerates technology development and innovation for a sustainable society.

**The Japan Organization for Metals and Energy Security (JOGMEC)** was established in 2004 as a key coordinating body in Japan's strategic approach to securing essential metals and energy resources (JOGMEC n.d.). Operating as a subsidiary of the METI, JOGMEC functions independently as a government-administered institution, primarily executing METI's policies while supporting private Japanese companies. JOGMEC plays a critical role in assisting Japanese companies to mitigate various risks related to the exploration of critical resources as well as their acquisition. Its support is multifaceted, encompassing three primary measures: (1) providing financial assistance, (2) facilitating joint venture explorations, and (3) fostering international cooperation. The organization particularly focuses on joint exploration ventures in resource-rich regions like Africa and South America, seeking to expand Japan's access to crucial minerals and energy resources. One of JOGMEC's notable investments includes a substantial financial commitment of AU$ 200 million in Lynas Rare Earths Ltd., an Australian mining company (CISL and Wuppertal Institute 2023). This investment exemplifies Japan's broader strategy of securing essential resources through international partnerships and strategic financial engagements.

In February 2021, the **Global Alliance for Circular Economy and Resource Efficiency (GACERE)** was launched. The alliance includes members from Japan, the EU, and other countries from the global North and South. Its purpose is to share good policy practices, support partnerships, and facilitate global conversations on the governance of natural resources (Ito 2022).

Other multilateral cooperation formats, in which Japanese ministries are highly involved, focus on high-level policy-makers, such as the **Regional 3R & CE Forum in Asia and the Pacific** (MOE o.J.) as well as more local approaches to knowledge sharing, such as the **African Clean Cities Platform (ACCP)** (UNEP 2022).

The **Japan Partnership for Circular Economy (J4CE),** initiated by the METI, and the Japan Business Federation, showcases Japan's collaborative business approach as well as collaborative approach towards sustainability. Launched in March 2021, J4CE aims to enhance public-private partnerships, promoting the circular economy's understanding across various stakeholders. With over 100 companies joining shortly after its inception, J4CE showcases a commitment to advancing circular economy initiatives, focusing on prioritiy sectors of global interest, among them batteries (J4CE 2021).

### 4.2.3 Industry best practices for circular economy solutions for CRMs for energy transition technologies

There are a number of Japanese, companies, that successfully apply CE strategies in their business model described in chapter 4, which by extention leads to keeping the CRM in the loop for as long as possible. The info boxes below present some examples of selected best practices. The selection aims to cover different energy transition technologies and is not comprehensive.

**Reuse, Remanufacture & Recycle: New life for broken solar PV panels and impure silicon – Eiki Shoji Co Ltd**

As described in chapter 4.2.1 Japan, as other countries which utilize solar energy, faces challenges in managing PV waste, with rapid growth in solar energy installations leading to increasing volumes of end-of-life solar panels. This issue poses a challenge for waste management and resource recovery, as discarded panels contain valuable materials that can be reused or recycled. However, the country has been proactive in addressing these challenges through innovative approaches to recycling and repurposing PV panels.

**Eiki Shoji Co Ltd** is a Japanese renewable energy company with its headquarters in Tokyo and has 91 employees. The company operates a business focused on reusing, repairing, and recycling solar PV panels. They acquire defective panels or excess inventory from manufacturers, systematically sorting and dismantling them for subsequent repair and restoration. The revitalized panels find new use, including deployment in Congo, Indonesia, Myanmar, Nepal, and Uganda (Bangert 2020). Furthermore, the company is also active in recycling of office automation equipment and personal computers. The therefore sort out the valuable materials such as circuit boards and LCD panels and resell them, including overseas. The recycled products are also sold on their e-commerce site, leading to the reuse and effective utilization of resources. The company also purchases silicon that is no longer utilizable from silicon refiners and recycles it as a raw material for solar power generation equipment. Silicon, as an essential material for semiconductors, must be refined to an ultra-pure level of almost 100 %. In contrast, the purity required as a raw material for solar power generation equipment is slightly less, but still way over 99.99 %. Hence, the material can still be of use there (Eiki Shoji 2023).

**Recycle: Valuable metals from electronic components – Asteric Irie Co., Ltd.**

The generation of e-waste is expected to exceed 75 million tons by the year 2030, wih Asian countries being one of the major contributors to the e-waste generation (Yoshida 1/25/2024). However, this scrap contains various precious and rare earth metals which can be utilized as input for production of other technologies. Japan targeted this issue by establishing relevant policies supporting recycling of e-waste, such as the Small home appliances recycling act, 2013 and the Home appliances recycling act 2001 (Nagasaki 2024) and is the frontrunner in recycling of e-waste (Yoshida 1/25/2024).

**Astec Irie Co., Ltd.** has over 740 employees and is located in the city of Kitakyūshū. The company offers different products and services, from support to steelmakers in the production process to producing steel pipes themselves, used for example for the automotive or petroleum industry.

Alongside, the company is active in so-called urban mines recycling, meaning they conduct recycling processes to extract metals from waste electronics, like circuit boards in computers or mobile phones. Used electronic devices contain many electronic components and are fixed with solder, etc., so they must be removed (Astec irie 2023). Furthermore, since the amount of useful substances such as repellent substances and precious metals contained differs depending on the type of electronic part, it is necessary to further sort the removed electronic parts.

Astec Irie Co., Ltd. has developed a method that combines iron chloride recycling and superheated steam to extract and sort these electronic components, contributing to the recycling of valuable metals like gold, copper, nickel and palladium. The company also applies AI technology to sort small electronic parts, that would not have enough value to sort by manual labor. The AI is still in the developing phase, but able to select parts with a probability of 90 % (Takahashi et al. 2021).

**Reuse & Recycle: Second life for lithium-ion battery cathodes – JERA Co., Inc. and Sumitomo Chemical Co., Ltd.**

With the expected increase in electric vehicles to achieve carbon neutrality, Japan, a country with scarce natural resources, must prioritize the separation and collection of rare metals from used batteries. in an efficient and environmentally friendly way in order to reuse them as battery materials (JERA Co., Inc. 2022).

**JERA Co., Inc.** and **Sumitomo Chemical Co., Ltd.** have received a grant from NEDO's Green Innovation Fund Programme to carry out a project to develop a process for reusing parts of the lithium-ion batteries for electric vehicles (JERA Co., Inc. 2022). The existing recycling methodology not only contributes to GHG emissions but also leads to the oxidation and breakdown of materials, thereby hindering the efficient recovery of rare metals. This initiative focuses on overcoming these obstacles by creating a green process for recycling lithium-ion batteries from electric vehicles. The endeavor is scheduled to progress from 2022 through 2030 (JERA Co., Inc. 2022).

JERA is developing a new method for separating and collecting battery materials in collaboration with Waseda University and Kumamoto University (JERA Co., Inc. 2022). Sumitomo Chemical, in collaboration with Kyoto University, will develop a new technology to recycle the cathode materials separated and collected by JERA without returning them to metal (JERA Co., Inc. 2022).

**Reuse, Refurbish, Recycle: Japan's first solar panel reuse platform – Marubeni Corporation and Hamada Co. Ltd.**

In anticipation of a large volume of used material as Japan's early solar installations are phased out, recycling companies estimate that 800,000 tons of solar panels will be retired each year from 2040 (Hamada Co. Ltd. 2022). So far, initiatives for reuseing solar panels in Japan have stalled due to difficulties in guaranteeing their quality (Marubeni Corporation et al. 2022).

**Marubeni Corporation**, and **Hamada Co. Ltd**., are forming Rexia Corporation to provide reuse and recycling services for solar PV panels, including the purchase and resale of used panels (Marubeni Corporation 2023). A key part of the solution will be an online platform for buying and selling used panels (Bourne 2023). The platform will contain information such as panel specifications, usage history and performance data, and also support requests for recycling services (Bourne 2023). Rexia aims to provide services to evaluate and purchase panels based on an established performance testing methodology. Panels can then be sold with a product warranty (Marubeni Corporation et al. 2022).

# 5 Existing forums of German-Japanese cooperation

Germany and Japan have already developed various dialogue platforms for bilateral and multilateral exchange on issues relating to the sustainable supply of CRMs, particularly in light of the rising demand for raw materials for the energy transition. In some instances, CE is already being discussed as one solution.

In March 2023, the governments of the Federal Republic of Germany and Japan published a **joint declaration as part of the first German-Japanese government consultations**, in which greater cooperation in securing access to sufficient supplies of CRMs, explicitly also for clean energy and batteries, was agreed. In this context, the CE is also mentioned as a strategy for promoting access to CRMs. The joint declaration stipulates that the respective national resource agencies (JOGMEC in Japan and BGR in Germany) will cooperate more closely and exchange knowledge on issues relating to the secure supply of critical minerals (Die Bundesregierung 2023a).

The **Japanese-German Energy Partnership** was established between BMWK and METI in 2019 to strengthen the cooperation between both countries on the energy transition. During the Energy Partnership's cooperation committee meeting in November 2023, the topic of alternative PV technologies such as perovskite solar cells was put on the agenda for the future cooperation with the target to exchange on possible ways to reduce dependence in supply chains and related CRM. Additionally, the 13th edition of the German-Japanese Environment and Energy Dialogue Forum (EEDF), the flagship public event of the Energy Partnership, was dedicated to the topic of "circular economy for climate action" in January 2024, with two dedicated sessions on the nexus of the energy transition and circular economy.

During the two consecutive G7 presidencies of Germany (2022) and Japan (2023), the two governments have also reinforced their intention to strengthen cooperation in the area of economic security (Die Bundesregierung 2023a). Under the German G7 Presidency in 2022, for example, the so-called "**Berlin Roadmap**" was adopted, in which the G7 member states committed themselves to jointly strengthening resource efficiency and the CE and set targets for the period 2022 to 2025, including increased exchanges between member states on topics such as the eco-design of products, circular business models and green public procurement (GPP) (G7 2022). In 2023, under the Japanese G7 presidency, the **Circular Economy and Resource Efficiency Principles (CEREP)** were adopted, a set of behavioral guidelines to promote the CE and resource efficiency in the private sector (G7 2023).

During its G7 presidency in 2015, Germany also initiated the **G7 Alliance on Resource Efficiency (ARE)** as a voluntary forum, placing resource efficiency as a fixed topic on the G7 agenda. Within the framework of the G7 ARE, Japanese, German and other G7 policy makers are working together to promote international dialogue on issues of resource efficiency and CE and to bring experts on the topic together. During the 2023 G7 ministerial meeting on climate, energy and environment in Japan, a five-point plan for CRMs security was announced, in which the G7 members recognise recycling as a central strategy for securing access to CRMs, in particular the recycling of old lithium-ion batteries and neodymium magnets (G7 Ministers 2023). The G7 ARE also co-operates with other international forums on this topic, in which Germany and Japan are also represented (G7 Alliance on Resource Efficiency n.d.). These include the **G20 Resource Efficiency Dialogue**, which was launched in 2017 under the German chairmanship at the G20 summit in Hamburg. In 2019, the G20 Resource Efficiency Dialogue took place in Tokyo under the Japanese chairmanship and, with the support of METI, a website was set up for the exchange of information within the framework of the G20 dialogue, which is managed by IGES. The G20 Resource Effiency Dialogue also promotes sustainable use of natural resources and holds regular meetings (IGES n.d.).

Both Japan and Germany have also been steering committee members of the **International Resource Panel (IRP) established under UNEP** since 2007. IRP is a global science-policy platform for the exchange of knowledge on the utilisation of natural resources. The common goal is to develop approaches to move away from excessive resource consumption by implementing resource efficiency. As part of its programme "Building Resilient Societies after the COVID-19 pandemic", among other things, the implementation of circular approaches as a concrete approach to reducing the consumption of primary raw materials is being discussed (UNEP n.d.).

Germany and Japan are both members of the **International Minerals Security Partnership (MSP)**, which was announced in 2022 under US leadership. The MSP aims to establish robust supply chains for CRMs while protecting the environment. Participants in the MSP have committed to funding international endeavors across the entire supply chain, including the advancement of recycling technologies. (CISL and Wuppertal Institute 2023; U.S. Department of State n.d.).

In addition, Japan is a close cooperation partner with the EU in various formats on issues of raw material security and CE. Most recently, an **Administrative Arrangement** was signed between the EC and JOGMEC at the EU-Japan summit on July 6, 2023, reinforcing the bilateral cooperation on CRM supply chains (EC 2023a).

# 6 Comparison

Japan and Germany are both among the countries with the highest energy consumption worldwide (Enerdata 2023). Both countries have set clear targets to achieve climate neutrality - by 2045 for Germany and by 2050 for Japan. This goal is to be accomplished through the significant expansion of renewable technologies, including on-shore and off-shore wind and solar power. Germany has led this transition, initiating its shift towards renewables earlier with ambitious targets, especially in wind and solar energy. In contrast, Japan, while also aiming for a significant renewable share by 2050, is also incorporating nuclear energy and Carbon Capture and Storage (CCS) into its decarbonization strategy. Despite differing paces and strategies, both countries acknowledge the essential role of CRMs to achieve their climate goals.

With regards to key CRMs, necessary for clean energy transition technologies, neither Japan nor Germany have significant local mining capacity and are therefore heavily dependent on imports from third countries, particularly China. Both governments have recognized supply security and the high greenhouse gas emissions associated with the primary extraction and processing of CRMs as significant challenges. These concerns are reflected in recent strategies aimed at securing future sustainable access to CRMs, such as Germany's Raw Materials Strategy of 2020 and Japan's Policy on Measures to Ensure Stable Supplies of Critical Minerals of 2023.

In Germany, this represents a somewhat new approach, as the security of commodity supply has traditionally been seen as a responsibility of the industry, with little state involvement (for example, there are no significant public participations in mining companies, no establishment of national stockpiles, etc.). This is also reflected in the fact that central coordination bodies such as the DERA were only founded in 2010.

Partly due to experiences with supply bottlenecks caused by geopolitical tensions with highly important suppliers compounded by the country’s isolated location, Japan introduced relevant policy frameworks and financial support measures to stabilize access to CRMs as early as 2004 and prioritizes general supply security over market efficiency in its raw materials policy. For example, the 2020 International Resource Strategy provides for the development of national stockpiles. In addition, the central Japanese coordination body JOGMEC has been providing financial support to mining companies since 2004 and in some instances also participates directly in mining projects abroad.

Despite the described differences in their overall approaches to securing access to CRMs, both Japan and Germany have identified dependencies on imports and high GHG emissions associated with the extraction and processing of virgin CRMs as key challenges for the clean energy transition. In response, both countries have developed strategies that recognoze the the potential of the CE to reduce import dependencies and achieve parallel reductions in GHG emissions. This shared political vision is also reflected in the close cooperation between Germany and Japan in various bilateral and multilateral forums. During their successive G7 presidencies in 2022 (Germany) and 2023 (Japan), the topic of CE and resource efficiency for CRMs was recently consolidated as a topic on the multilateral agenda.

As illustrated by Figure 4 and Figure 5, in both countries, various policies, strategies and instruments have been adopted that strengthen the concept of CE overall and already contain some approaches for implementing CE to secure the most sustainable access to CRMs in important energy transition technologies. With the publication of the Act on Promotion of Use of Recyclable Resources (1991) (1R), the first Circular Economy Vision in 1999 (3Rs) (updated in 2020) and the Basic Act on Establishing a Sound Material-Cycle Society in 2001, along with the Law on Promotion of Effective Utilization of Resources, Japan was early in establishing the CE as a guiding political principle in its sustainability policies and can therefore be described as a pioneer in the political promotion of the "3Rs" reduce, reuse and recycle. The Japanese infrastructure is particularly advanced in the area of recycling: 98 % of all metal waste is recycled and Japan is recognised globally for its expertise in the field of recycling and substitution. Japan has implemented several policies and measures targeting the recycling and reuse of electronics, automobiles, and other critical components. The Home Appliance Recycling Law, enacted in 2001, mandates the recycling of major appliances, while the End-of-Life Vehicles Recycling Law (2005) aims to make the automotive industry in Japan the leader in CE promotion of material recycling of vehicle parts. The issue of waste and challenges of waste management for clean energy technologies as well as storage technologies are under discussion in several METIs study groups. For example, the issue of increasing PV-waste has been recognized and addressed by developing targeted guidelines for waste management of solar PVs. Similar discussion is in progress for wind turbines. While the stable CRM procurement for battery production is included in Japan’s Battery Industry Strategy (2022), the end-of-life treatment of batteries is under the discussion by METI's "Study Group on Sustainability of Storage Batteries."

Furthermore, Japan's strategic emphasis on innovation and technology for sustainable CE practices is evident in the "Strategy for a Growth-Oriented, Resource-Autonomous

Circular Economy" launched in March 2023, aiming to establish a self-reliant domestic resource circulation system and deepen the 4R policy. This strategy supports CE investment, digitalization, and start-up ventures, which highlights Japan's approach to CE and CRM. The role of financing in supporting Japan's CE and CRM initiatives is highlighted by the Green Bond Guidelines and the Disclosure and Engagement Guidance to Accelerate Sustainable Finance for a Circular Economy, demonstrating the significance of financial mechanisms in advancing sustainable resource management.

Germany overall has a good collection and recycling infrastructure, which in principle allows for the introduction of CE approaches, and good recycling values are achieved already in the area of bulk metals. While overall recovery rates for special and some industrial metals are currently low, some German companies are piloting innovative processes for the high-quality recovery of CRMs, including from energy transition technologies (cf. chapter 4.1.3). The framework conditions for this are provided by a wide range of different political programs and funding instruments: The first comprehensive legislation on CE approaches in Germany, the Circular Economy Act (KrWG), was passed in 2012 (updated in 2020). Requirements for the return and recycling of CRMs with particular significance for energy transition technologies are also described by an increasing number of different product-specific regulations such as the Batteries Act (2009, updated 2021) and the Electrical and Electronic Equipment Act (2015, updated 2022), which includes provisions for the EOL treatment of solar PVs. A number of initiatives to develop sector-specific regulatory changes and regulations for a holistic approach to CE (e.g. with regard to ecodesign) have also been launched at European level, particularly since the beginning of the Russian war of aggression on Ukraine in early 2022, which has put a renewed focus on the vulnerability of global supply chains in Europe. Both the German Standardisation Roadmap Circular Economy published in 2023 as well as the National Circular Economy Strategy (2022) and the EU 2020 Circular Economy Action Plan (CEAP) make proposals on how the various approaches and strategies for achieving closed loop production circles and resource efficiency can be streamlined. This can also help to disseminate various CE business models that are being piloted in Germany (e.g. testing and distribution of Second Life batteries and solar panels), as described in chapter 4.1.3.

The overview of policies and industry best practices in Germany and Japan shows that traditionally, the understanding of circularity was often limited to recycling, with many previous policies specifying only quantitative collection and recycling quotas (Tedesco et al. 2023; CISL and Wuppertal Institute 2023). However, as described in chapter 4, a fully functional CE model also entails more holistic approaches such as Remanufacture, Rethink, Refurbish etc. which have not been sufficiently encouraged by policies (CISL and Wuppertal Institute 2023). It can be observed that more recent policies recognise this and are introducing new provisions and supporting schemes for the implementation of a wider range of CE approaches to CRMs and energy transition technologies. This trend is reflected, for example, in the provisions of the German Batteries Act and the Electrical and Electronic Equipment Act requiring battery and solar PV manufacturers to increase the durability and reusability of their products. Another example is the introduction of preferential principles for sustainable products in public procurement decisions in the Circular Economy Act and several pieces of legislation proposed/adopted at EU level in recent years. These include the new EU Battery Directive which, amongst other things, introduces a digital product passport (DPP) or the proposal of an updated Ecodesign for Sustainable Products Regulation (ESPR) which introduces product design provisions that allow for improved reusability of products.

In Japan, too, where CE policies have historically focused heavily on recycling (1R), new policies, measures and initatives recognize the importance of other lifecycle aspects of products. For example, in Japan, the importance of circular design is recognized with the 2020 Guidelines for Environmentally Conscious Design of PVs. Additionally, efforts are being made to use alternative materials for producing solar panels, such as perovskite PVs, to substitute CRMs. The National Hydrogen Strategy (2023) emphasizes the importance of policies for recycling renewable energy and rare metals, crucial for electrolysis and fuel cells, and advocates for technology that reduces rare metal use.

Furthermore, policies related to the repair and recycling of batteries, including targets, are currently under discussion. Similar to Germany, Japan promotes the procurement of environmentally friendly products through its green public procurement policy, the Green Purchasing Act (2001).

While both Japan and Germany have introduced initial policy measures and instruments to promote CE solutions specifically for batteries and solar PVs, there are comparatively few approaches for wind energy and hydrogen/electrolyzers, which are also key technologies in the energy transition in both countries. While general commitments to promoting R&D for resource efficiency and CE are included in the national hydrogen strategies of both countries, there are currently no comprehensive roadmaps available that define a longterm and standardized approach.

Overall, Japan and Germany show an equal level of ambition in the targets they have formulated for strengthening CE approaches to CRMs for energy transition technologies. This invites to further knowledge exchange and cooperation between Japanese and German stakeholders in order to support the further development of specific approaches to enhance CE in the field of CRM for the clean energy transition.

# 7 Conclusion and topics for German-Japanese cooperation

As like-minded partners, both Japan and Germany have fundamentally committed to strengthening CE approaches within their economies and have also recognized the potential of CE to secure sustainable access to CRMs.

Both countries have begun to introduce legislation that also covers CRMs relevant for the energy transition. This acknowledgment of the necessity for more comprehensive action underscores the importance of comprehensive solutions that involve circularity. Such foresight ensures that CRMs from energy transition technologies are readily available for low-emission domestic recycling and reuse in the future. Recent legislative developments as described in detail in chapters 4.1.1 and 4.2.1 are essential in securing a sustainable supply of CRMs, pivotal for both countries' transition to cleaner energy supply and the broader adoption of CE principles. However, there are few technology-specific regulations along with concrete targets for disposal, reuse and recycling of energy transition technologies at their EOL stages, especially in the case of wind power and electrolyzers. With regards to EV batteries and PVs there are requirements regarding EOL management which does strengthen the recycling, however other approaches like reuse or refurbish, are less promoted by the existing regulatory framework.

Overall, it is important to highlight that strengthening CE is a complex endeavour, as many different areas either require a tightening of existing regulations (such as regulations regarding the export of EOL solar PVs, so that recycling does not take place abroad and thus CRMs are lost), or an adjustment (for example, some guidelines on EOL treatment, e.g. of batteries, would need to be adjusted to enable reprocessing and reuse). Additionally, many of these technologies are undergoing continuous change: the composition and use of various CRMs can differ significantly between individual technologies, and therefore very specific guidelines, for example regarding recovery rates of individual raw materials, might not prove to be beneficial. Nevertheless, there are several areas where policymakers can act to strengthen the implementation of CE approaches. Table 1 outlines key recommendations for cooperation and mutual learning between Germany and Japan.

As global frontrunners for the use and production of certain energy transition technologies and in high-quality **recycling**, policy decisions made in Japan and Germany on the topic can influence the global market and technological pathways in recycling CRMs and energy transition technologies. For wind turbines and electrolyzers in particular, Japan and Germany can provide impetus for the global promotion and design of CE approaches for the preservation and recovery of CRMs, as they dominate significant shares of global production in these areas. Against this background, political decision-makers participating in the dialogue are encouraged to discuss innovative approaches for strengthening recycling technology, infrastructure and quality:

- Joint identification of specific energy transition technologies for which there is the greatest potential for influence through the introduction of CE approaches due to the market shares etc. of Germany and Japan.
- Exchange on the introduction of mandatory levels of recycled content under specific technologies, as contained in the new EU Battery Directive, for example, and necessary accompanying support measures for implementation.
- Exchange on the design and effective implementation of collection and recycling quotas at the EOL as well as product-specific EPR with take-back systems, as contained i.e. in the German Batteries Act and the Electrical and Electronic Equipment Act.
- Exchange on the effective design of investment strategies and financial mechanisms such as public loans to support R&D in high quality recycling, collection, sorting and processing.

In addition, Japanese and German policy makers should discuss enforcement strategies to ensure that, for example, politically defined recycling quotas are actually met. This can include public awareness campaigns, incentives for recycling, and more convenient recycling infrastructure as well as robust monitoring systems. Learning from each other's policy successes and setbacks can lead to the development of more effective political frameworks and interventions. The similarities and differences in legislative and policy frameworks that support recycling initiatives, including the effectiveness thereof, can serve as discussion point for mutual learning.

In the area of **reuse** and **reduce**, both countries have begun to implement initial ideas and approaches, including circular product design. An exchange on uniform design standards, for example, can provide important insights at an early stage and enable international standards to be aligned as closely as possible. In particular, the following topics arise for an exchange between the responsible ministries and authorities:

- Exchange on and harmonization of the creation of mandatory design criteria and standards for producers to design and manage their products dureable, reusable and recyclable, e.g. based on the example of Japan's

Guidelines for environmentally conscious design of solar installations (published by MOE in 2020) and initial suggestions provided in the German Standardisation Roadmap Circular Economy of 2023, and expected provisions for solar PVS in the updated EU Eco-design Directive.

Both countries could engage in a structured comparison and exchange of their design requirements and initial findings related to environmentally conscious and circular product design. Understanding the specifics of Japan's guidelines, including criteria and implementation strategies, could inspire similar or complementary guidelines within the German context. Similarly, Japan can benefit from insights into Germany's initial design considerations. Through the comparison and exchange of design standards and guidelines, Germany and Japan could identify areas for collaborative development of global standards for sustainable and circular product design. Collaborating on global standards could facilitate trade, ensure compatibility of solar installations across markets, and encourage the global adoption of environmentally friendly and circular design practices.

In order to target the **reduced** use of CRMs in energy transition technologies, their substitution with i.e. more easily recyclable materials could be discussed. A particularly interesting topic for bilateral exchange could be:

- Exchange learnings from alternative materials research. Japan has been the long time global leader in patent filings for the manufacturing of "next generation" perovskite PV modules to replace CRMs (Kusashio and Fukui 2023) and could also share interesting findings from the implementation of R&D funding andsupport in this area, i.e. via the NEDO Green Innovation Fund projects.

In addition to the selected approaches for promoting specific CE approaches for CRMs for energy transition technologies, there are some more general policy measures that can enable or strengthen the implementation of CE approaches overall. Here, too, German and Japanese policy makers can learn from each other:

- Exchange on how sustainable public procurement requirements can further boost the market for sustainable and circular products, for example, when purchasing solar PVs or storage systems for installation on and in public buildings.
- Exchange ideas on how the governments of both countries could jointly work together to promote demand for circular products and establish "circular lead markets" (based on debates on "green lead markets"). Especially for energy transition technologies such as electrolyzers and wind turbines, Japan and Germany have good opportunities to lead the discussion e.g. on standardized definitions of "circular wind turbines" and to develop policy instruments that strengthen demand and trade in such technologies.

According to the OECD, in 2021, public procurement amounted to around 18 % of GDP in both Germany and Japan, well above the OECD average of 12,7 % (OECD 2023). Sustainable or green public procurement thus has great potential to play a pioneering role in sustainable purchasing decisions and can strengthen new, circular business models. In addition, there is potential for cooperation and exchange between the two partners in the following fundamental area:

- Exchange on policy measure that improve the information base and data compatibility for circularity, i.e. via the introduction of Digital Product Passports (DPPs) as foreseen in the new EU Battery Directive and mentioned in the EU ESPR draft.

The transparent and standardized provision of product data to all stakeholders along a product's life cycle and supply chain can not only boost material and energy efficiency and recyclability, but also enable new business opportunities, such as extending product life through product-as-service activities or repair and remanufacturing. Improved information provision can further support consumers in making sustainable consumption decisions and empower authorities to more easily verify compliance with legal obligations. The establishment of a DPP can thus be an interesting topic for Japanese stakeholders to consider. Furthermore, it should be ensured that the requirements for filling the DPP, for example for batteries, are compatible with international standards and norms so that battery manufacturers can develop compliant approaches. An early exchange between Germany and Japan can avoid compability issues later on.

Furthermore, Germany could learn from Japan's collaborative business model, as exemplified by the Japan Partnership for Circular Economy (J4CE). This initiative demonstrates how fostering public-private partnerships can promote a deeper understanding of the circular economy among a broad number of stakeholders. Germany, with its strong industrial base and commitment to the energy transition, could learn from Japan's approach by enhancing cooperation between government, industry, and academia. Such collaboration could accelerate Germany's own circular economy initiatives, ensuring a secure and sustainable supply of CRMs and a close collaboration with the industry.

The discussion of CE and CRM topics can be facilitated through a variety of formats designed to foster collaboration between Germany and Japan. These can range from policy exchanges at the working level of public administration, supported by policy analyses prepared by German and Japanese research teams with coordinated funding. In addition, practitioners from business and civil society organisations should be included in bilateral exchange formats. This is already successfully done within the two working groups established within the Japanese-Germany Energy Partnership on topics regarding the "Energy Transition" and "Hydrogen". A dedicated sub-working group on issues regarding "CE approaches for the energy transition" or "Secruing CRMs for the energy transition" or broader on "Resilient and Sustainable Supply Chains for the Energy Transition" could provide a suitable framework for a cross-stakeholder exchange on these topics. Additionally, the establishment of joint expert pools, policy dialogues, and business dialogues can further enrich the conversation. Long-term sustainability and circularity partnerships between researchers, underscored by research dialogues, also play a critical role. Japanese researchers' involvement in various EU Horizon 2020 projects exemplifies the potential for deep collaboration and shared learning in advancing CE and CRM initiatives (EU-Japan Centre for Industrial Cooperation 2022). The other existing policy dialog formats between Japan and the EU are also to be continued and expanded to include discussions on the application of CE for CRMs relevant to the energy transition. The Administrative Arrangement between the EC and JOGMEC from July 2023 (EC 2023a) provides a suitable starting point and framework for this.

**Table 1: Areas for Japanese-German cooperation and mutual learning**

| Key CE approaches | Recommendations/tools to strengthen CE approaches | Examples/initial approaches |
|---|---|---|
| **Recycle** | • Mandatory levels of recycled content<br>• Mandatory collection & recycling quotas at the EOL<br>• Extended Producer Responsibility with take-back requirements<br>• Investment in R&D and public loans supporting high quality recycling, collection, sorting and processing | → EU Batteries Directive: mandatory minimum levels of recycled content for CRMs<br>→ Japan's Green Bond Guidelines: R&D investments |
| **Reuse / Reduce** | • Creation of mandatory design criteria & standards for producers to design and manage their products durable, reusable and recyclable<br>• Substitution of CRMs with materials that are more easily recyclable | → German Standardisation Roadmap Circular Economy & EU ESPR draft; Japanese Guidelines for Environmentally Conscious Design of PVs<br>→ Japan: NEDO Green Innovation Fund Projects and R&D for next generation PVs (perovskite) |
| **Other** | • Use the potential of sustainable/green public procurement as a booster for ircular and sustainable products<br>• Establish "circular lead markets" for innovative energy transition technologies<br>• Improvement of information base & data compatibility for circularity | → Germany's Circular Econoy Act and Japan's Green Purchasing Act<br>→ EU Batteries Directive: Digital Product Passport (also mentioned in EU ESPR draft) |

# List of abbreviations

| | |
|---|---|
| 3Rs | reduce, reuse, recycle |
| 3R Act | Resource Effective Utilization Promotion Act |
| ACCP | African Clean Cities Platform |
| ARE | G7 Alliance on Resource Efficiency |
| BASC | Battery Association for Supply Chain |
| BGR | German Federal Insitute for Geoscience and Natural Resources |
| BImSchG | Federal Immission Control Act |
| BMBF | German Federal Ministry of Education and Research |
| BMUV | German Federal Environment Ministry |
| BMWK | German Federal Ministry for Economy and Climate Action |
| CCUS | Carbon Capture, Utilization, and Storage |
| CE | Circular Economy |
| CEAP | EU Circular Economy Action Plan |
| CEREP | Circular Economy and Resource Efficiency Principles |
| COP | Conference of the Parties/ United Nations Climate Change Conference |
| CRMs | Critical Raw Materials |
| CRMA | Critical Raw Materials Act |
| DERA | German Raw Materials Agency |
| DPP | Digital Product Passport |
| EC | European Commission |
| EEDF | Environment and Energy Dialogue Forum |
| EEG | German Renewable Energy Sources Act |
| EIP | European Innovative Partnership |
| EIT | European Institute of Innovation and Technology |
| ElektroG | Electrical and Electronic Equipment Act |
| EOL | End of Life |
| ESPR | Ecodesign for Sustainable Products Regulation |
| EVs | Electric Vehicles |
| GACERE | Global Alliance for Circular Economy and Resource Efficiency |
| GERRI | German Resource Institute |
| GHG | Greenhouse gas |
| GPP | Green Public Procurement |
| GW | Gigawatts |
| GWh | Gigawatt-hour |
| GX | Green Transformation |
| ICT | Information and communication technology |
| IEA | International Energy Agency |
| IGES | Institute for Global Environmental Strategies |
| IRENA | International Renewable Energy Agency |
| IRP | International Resource Panel |
| J4CE | Japan Partnership for Circular Economy |
| JAMA | Japan Automobile Manufacturers Association, Inc. |
| JOGMEC | Japan Organization for Metals and Energy Security |
| JPEA | Japan Photovoltaic Energy Association |
| JPY | Japanese Yen |
| JWPA | Japan Wind Power Association |
| JSWTA | Japan Small Wind Turbine Association |
| KrWG | Circular Economy Act |
| kt | kiloton |
| METI | Japanese Ministry of Economy, Trade, and Industry |
| MOE | Japanese Ministry of the Environment |
| MSP | International Minerals Security Partnership |
| MUFG | Mitsubishi UFJ Ginkō bank |

| | |
|---|---|
| Mt | Megaton |
| MW | Megawatt |
| NKWS | National Circular Economy Strategy |
| NEDO | Japanese New Energy and Industrial Technology Development Organization |
| PVs | Photovoltaics |
| R&D | Research and Development |
| REEs | Rare Earth Elements |
| t | ton (metric) |
| TWh | Terrawatt hour |
| UBA | Federal Environment Agency |
| UN | United Nations |
| UNEP | United Nations Environment Programme |
| UNFCC | United Nations Framework Convention on Climate Change |

# List of figures

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