Climate Neutrality Foundation

Securing Germany's Sovereignty

Resilient supply chains for the transformation to climate neutrality by 2045

Condensed version of the study

prognos

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In addition, technical events were held with company and industry representatives from the fields of renewable energies, automobility and green steel.

We would like to thank everyone involved for sharing their expertise and experience. This professional exchange provided important impetus for the preparation of this study.

The study participants Prognos, Oeko-Institut and Wuppertal Institute as well as Climate Neutrality Foundation are solely responsible for the contents of this study.

Condensed version of the study

Securing Germany's Sovereignty

Resilient supply chains for the transformation to climate neutrality by 2045

With this study we seek to draw attention to key priorities, strategies and policy measures for "resilient supply chains" in order to secure the transformation to climate neutrality.

Contents

Dear Reader,

The past years have been characterized by far-reaching changes that have underscored the need for an accelerated and resilient transformation to climate-neutral economies. One such change is the fact that the impacts of the man-made climate crisis are becoming increasingly noticeable around the world. In addition, the Russian invasion of Ukraine has provided a particularly clear demonstration of the vulnerability of Europe's economy and society as a result of its dependency on fossil fuels, as well as the negative implications of one-sided import dependencies on certain countries. With the introduction of the Inflation Reduction Act (IRA) in the United States, it has also become very evident that the competition for establishing business locations for the key future technologies that are driving the transformation is in full swing. And there is China, which has been working successfully for more than a decade to become the world market leader in green technologies.

The European Union and Germany must ensure that the necessary transformation to climate neutrality takes place in a resilient way. In the context of this study, resilience is understood as the ability to withstand external shocks or upheavals within the social, economic or political framework, in particular with regard to international embedding, as well as the ability to adapt to the new conditions. For key technologies along the entire supply chain, this means possessing the necessary technologies and components, securing the key raw materials, implementing appropriate diversification strategies and establishing a recycling economy at an early stage. Only if these measures succeed will the European Union and Germany be able to implement the transformation, play a strong role on the global market in the future and provide future-proof jobs at home, thereby securing national and European sovereignty. Ultimately, Europe will only enjoy the necessary political leeway for sovereign action if the European Union and its Member States cannot be unilaterally blackmailed when it comes to central issues of economic prosperity. When it comes to transformation, therefore, the issue of resilient supply chains is therefore more than an economic question or challenge, it is rather a highly political question of national security and national sovereignty.

With this study, we will address the various dimensions of the formulated challenges in order to help decision-makers quickly and effectively implement strategies and measures that will advance a resilient transformation.

- We will identify the key technologies, intermediate products and raw materials which are of key relevance in the transformation to climate neutrality, and which should be prioritized and secured by the respective political stakeholders.
- We will analyze the central supply chains and point out individual area of weakness. The technologies required for the transformation can only be considered to be secure and available if all parts of the supply chain are robust. That is what is meant by resilience.
- We will recommend solutions for each of the key technologies and formulate recommendations for initial political decisions.

The study presented here pertains first and foremost to Germany, thus providing concrete recommendations for action for a key EU Member State on the one hand, while on other hand charting a viable approach to complex questions that must also be addressed at the wider EU level. With this study, we would like to draw attention to key priorities, fields of action, strategies and political measures for "resilient supply chains" in order to secure the transformation to climate neutrality and thereby strengthen the political sovereignty of Germany and the EU. We look forward to continuing our exchange with you.

Yours sincerely,
Regine Günther

Key findings of this study

1. A number of **key industries play a strategic role** in the transformation to climate neutrality. The strategic significance of these industries is central to the success of climate protection strategies, the political sovereignty of Germany and Europe as well as the securing of industrial locations. Among the particularly relevant key technologies are the following:
   - Photovoltaics
   - Wind power
   - Lithium-ion batteries for electromobility
   - Permanent magnets for electromobility and wind power
   - Electrolyzers
   - Heat pumps
   - Green steel plants (DRI shaft furnaces)

2. When assessing the level of resilience, it is necessary **to always take the entire supply chain into consideration.** The resilience of the supply chain as a whole is only as robust as that of the weakest link.

3. **For the key technologies, seven raw materials** are **categorized as critical** for the purposes of this study, with regard to extraction and processing. **Criticality can be managed through decisive political action.** *These raw materials are the following:* ***graphite, iridium, cobalt, lithium, manganese, nickel, as well as light and heavy rare earths.*** These materials are of particular significance with a view to the transformation phase until 2030/35.

4. **Targeted investments in domestic transformation industries and the locating of particularly critical parts of the supply chain in Germany or Europe enable the successful and resilient transformation to climate neutrality.** Of particular relevance in this context are the PV industry (specifically ingots / wafers, solar glass, PV cells / modules), the manufacturing of permanent magnets and their preliminary products (especially for wind turbines and electromobility), the complete supply chain for lithium-ion batteries (electromobility), and the development of a lead market for green steel.

5. **The international diversification in the procurement of critical raw materials, components and strategic goods** can be decisively supported by building transformation-oriented partnerships, thereby reducing market concentrations and dependencies. It is also especially important to establish and promote the further development of new trade relations. The following countries outside the EU are of particular interest for transformation-oriented partnerships: Australia, Brazil, Canada, Chile, Ghana, Indonesia, Canada, Colombia, Madagascar, Malawi, Mozambique, Namibia, South Africa, Zimbabwe.

6. A significant contribution from raw material recycling to building resilience is not to be expected before the early 2030s. At that point, however, the recycling of raw materials will begin to play an increasingly crucial role. It is essential, therefore, that efforts are already begun in the areas of recycling-friendly design of the relevant goods, timely investments in recycling capacities, and the development of a conducive industrial ecosystem.

7. Last but not least, the **reduction of raw material intensities and the development of alternative technology options** is an important pillar of a resilience-oriented transformation policy. To this end, it is essential to develop a corresponding environment for innovation in Europe.

Central strategies and instruments for bolstering resilience

1. **Introduce and institutionally anchor comprehensive resilience monitoring.** The regular analysis of raw material availability and supply relationships with critical dependencies along strategically relevant supply chains form the basis for policy decisions regarding necessary adjustments. Options for shaping institutional anchoring should be reviewed.

2. **Create stable domestic sales markets for transformative key technologies**. This can succeed by securing a stable political framework and reliable funding instruments in Germany and the EU. Funding for critical raw materials within the EU must be prioritized.

3. **Establish resilient-content guidelines.** This can be achieved by setting standards, for example on environmentally and socially acceptable criteria for funding measures and regarding the import of goods.

4. **Facilitate purchasing groups for strategic raw materials and goods as well as the bundling of supply contracts.** This can be achieved through a review and reform of antitrust law, as well as through bundling and securing procurement agreements through the public sector.

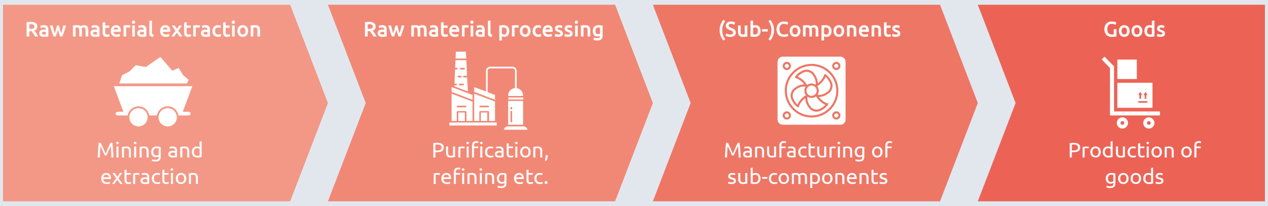
5. **Support an assertive approach to domestic business location policy in the area of strategic resources and goods.** This can be achieved through compensation measures for European transformation industries with a view to creating a level playing field vis-à-vis subsidized competitors outside of Europe. In this area, investment should be promoted and state aid for operational expenditures be made possible for a limited period.

6. **Expand and strengthen transformation partnerships on equal terms.** This can be achieved by strengthening economic cooperation beyond existing raw material and technology partnerships, by strengthening value creation in partner countries and by intensifying cooperation in education and research.

7. **Early-phase capacity building in the recycling industry.** This can be achieved by passing design requirements, export restrictions for secondary raw materials and primary products, and through the robust implementation of the EU Battery Regulation and the EU Critical Raw Materials Act.

We understand resilience as the ability to withstand external shocks or upheavals in social, economic or political framework conditions, in particular with regard to international embedding, and the ability to adapt to new conditions.

FIG. 01 **Stages of a Supply Chain – General Overview**
Critical supply situations can occur along the entire supply chain.



SOURCE Own depiction

Prognos, Oeko-Institut, Wuppertal Institut, 2023

1. Introduction

Germany has embarked on the path to achieving climate neutrality by the year 2045. In light of the changing geopolitical framework conditions, the question now arises as to how resilient supply chains are with regard to the expansion of transformation technologies.

This study examines the entire supply chain to determine where major dependencies on other countries exist in the supply of raw materials, components and strategic goods for the transformation of the economy, both now and in the foreseeable future, and what measures can be taken to bolster resilience. Since time is also a scarce resource on the path to climate neutrality, this paper will focus — regardless of the strategic target year 2045 — on the short and medium-term challenges leading up to 2030 and 2035 with regard to the resilience of relevant value chains.

This study is based on the baseline study "Towards a Climate-Neutral Germany by 2045" (KNDE2045),[1] written by Prognos, Oeko-Institut and the Wuppertal Institute and published in 2021. The basic assumptions of the precursor study have been retained, although adjustments and updates have been made to reflect current developments in the areas of transportation and the expansion of renewable energy.

The study "Securing Germany's Sovereignty – Resilient supply chains for the transformation to climate neutrality 2045" examines in detail the ramp-up over time of the raw materials, components and strategic goods required for the transformation of the respective sectors, and places them in relation to the current supply-side situation of the supply chains and their scalability in five-year steps from 2020 to 2045. This condensed version of the study presents the key findings in condensed form. The detailed analysis can be found in the full version.

This study focuses on the challenges that arise for the seven identified key technologies — photovoltaics, wind power, lithium-ion batteries, permanent magnets, electrolyzers, heat pumps and steel — primarily as a result of excessive dependence on foreign countries. The topics infrastructure, cybersecurity, shortage of skilled workers and bureaucracy, which are also relevant to the transformation, were not examined as part of this study.

1 Prognos, Oeko-Institut, Wuppertal Institute (2021): "Towards a Climate-Neutral Germany by 2045. How Germany can reach its climate targets before 2050." A study commissioned by Climate Neutrality Foundation, Agora Energiewende and Agora Verkehrswende. Online: https://www.stiftung-klima.de/app/uploads/2021/09/A-EW_213_KNDE2045_Summary_EN_WEB_v1.1.pdf

2. Risks along the supply chain and prioritization of key technologies

The criticality of raw materials, components and goods that are necessary for the transformation towards attaining climate protection targets depends on two main factors. For one, they must enable a significant reduction in greenhouse gas emissions in the short and medium term (2030/2035). Accordingly, the market ramp-up must be steep, with corresponding implications for the growth of the respective value chain as a whole. Secondly, a risk to security of supply exists or is foreseeable. Reasons for this can include:

- Excess demand: Demand outpaces the expansion of supply.

- Market power and concentration of supply: Many raw materials or intermediate stages in the value chain are concentrated on a very small number of countries, or are only extracted or produced by a few companies. This typically has both geological and historically-rooted reasons.

- In many resource-rich countries, a lack of or low level of environmental and social standards can be a major obstacle to establishing clean supply chains. While this aspect was not examined in this study, it is relevant for future analyses regarding the diversification of supplier countries.

It should be pointed out here that due to the special focus of this work, a definition of criticality has been chosen that includes criteria beyond the usual and established criticality analysis framework. Above all, this includes the focus on technologies that drive the transformation to climate neutrality, as well as a particular orientation towards future developments with a time horizon up to 2045, with a special emphasis on the period up to 2030/2035.

Today's debate about resilience in the context of the transformation to climate neutrality is often reduced to the availability of the required raw materials. A critical supply situation, however, can arise anywhere along the entire supply chain, whether during the extraction and processing of the raw materials, the production of the (sub-) components or the production of the individual goods. This is one of the factors analyzed in the context of this study.

Of over 30 transformation technologies, seven key technologies have been identified in a screening process, which were then prioritized and subject to further examination in light of the project goals.

The following criteria were decisive for the selection of these industries:

- Significant reduction in greenhouse gas emissions by 2030/2035
- Short-term steep ramp-up path
- Virtually no short-term alternatives
- High supply concentration of raw materials, components or even the production of whole goods.

The following seven key technologies emerged from the analysis:

- Photovoltaics
- Wind power
- Lithium-ion batteries for electromobility
- Permanent magnets for electromobility and wind power
- Electrolyzers
- Heat pumps
- Green steel plants (DRI shaft furnaces)

3. Key challenges to resilience across the entire supply chain of the seven key technologies

For the assessment of criticality, both the demand until 2045 and the current and foreseeable developments on the supply side along the entire supply chain were analyzed for the seven key technologies: From raw material extraction and processing to the production of (sub-) components up to the production of the individual goods, research was carried out based on currently available sources. By comparing findings related to the demand-side with supply-side findings, it was possible to categorize the stages of the supply chain as very critical, medium critical and moderately critical[1] for the purposes of this study. Figure 2 shows the main identified "Hotspots" regarding the resilience of strategic supply chains.

Overview: Criticality level by key technology

Photovoltaics: For wafer-based photovoltaics, while the actual extraction of raw materials is not in itself a vulnerable aspect, there are considerable challenges to the resilience of the value chain across the further processing stages. Above all, the production of ingots, wafers, solar glass and PV cells as well as modules is very critical due to China's highly dominant position, while the EU has little to no capacity of its own in this area. The processing of quartz sand into polysilicon is critical in part because China has a substantial market share here as well; however, there is one major producer of polysilicon located in Europe.

Wind power: For wind power (in particular offshore), as well as for electromobility, the main challenge for the resilience of the supply chain lies in the area of permanent magnets from rare earth elements. This is very critical because China dominates nearly all stages of the supply chain. Permanent magnets are now used in almost all new offshore wind turbines, as well as in around 20 percent of onshore wind turbines.

The manufacturing of offshore wind turbines is also currently associated with risks, as there is low production capacity, especially for large turbines over 12 MW. For the manufacturing of onshore wind power turbines, by contrast, there is still sufficient capacity in the medium term. However, the lower production costs in China compared to Europe could result in European manufacturers being squeezed out of the market. In addition, due to cost factors, a large number of components and sub-components are now purchased from Chinese companies. In contrast to permanent magnets, however, there is no monopoly in this area.

Electromobility: In the electromobility sector, large segments of the lithium-ion cell supply chain can be classified as very critical for purposes of this study. This begins with the supply of raw materials regarding the rapidly growing demand for key raw materials, primarily lithium, but also nickel, cobalt and graphite. China plays a very dominant role in the processing of raw materials (in particular graphite, manganese and cobalt). This also applies to subsequent stages such as the manufacturing of cathode material and, to an even greater extent, of anode materials. With regard to the production of the lithium-ion cells themselves, China currently also plays a leading role, followed by South Korea and Japan.

1 This categorization is project-specific with regard to the objectives of this paper. A direct comparison with other studies that make categorizations regarding the criticality of raw materials etc. (in particular the EU Critical Raw Materials List) is neither carried out here nor does it make sense, since the focus of this work is more specific than that of other publications.

FIG. 02 **Supply risks for strategic key technologies along the supply chain by criticality**
Risks differ according to their seriousness and the cause of possible supply bottlenecks.

	Raw material extraction	Raw material processing	(Sub-) Components	Goods
Photovoltaics		**Polysilicon:** China 79 %	**Ingots/wafers:** China 97 % **Cells:** China 85 % **solar glass**	**Modules:** China 75 %
Wind power			Many components are sourced in China	Currently sufficient capacity in Europe, but declining competitiveness
Generators and electric motors (for wind power and electromobility)	**Light rare earths:** China 58 % **Heavy rare earths:** China / Myanmar: 100 %	**Light rare earths:** China 87 % **Heavy rare earths:** China 100 %	**Permanent magnets:** China: 94 %	
Electromobility Lithium-ion batteries	**Lithium** **Cobalt:** Congo 72 % **Manganese:** South Africa 40 % **Nickel:** Indonesia38 % Graphite: China 73 %	**Lithium** **Cobalt:** China 75 % **Manganese:** China 95 % **Nickel:** China 55 % **Graphite:** China 100 %	**Cathode material:** China 71 % Anode material: China 91 %	**Battery cells**
Electrolyzers	**Iridium (PEMEL):** Extraction cannot be expanded. South Africa 85 % **Scandium** (HTEL, only after 2030/35)			
Heat pumps			**Compressors** (some with permanent magnets)	
Steel	**Iron ores** in DRI quality			**Plant construction:** for direct reduction plants (DRI shaft furnace)

LEGEND Concentration and market power; Short-/medium-term excess demand; Persistent scarcity
Criticality: Very critical; Medium critical; Moderately critical

SOURCE Own illustration

NOTE ON copper, titanium, gallium, germanium, yttrium and platinum: According to the investigations conducted in this study, these raw materials are strategically relevant for the transformation to climate neutrality to 2045, but not critical.

Prognos, Oeko-Institut, Wuppertal Institute, 2023

Electrolyzers: The main challenge for electrolyzers lies in the area of PEM electrolyzers. Here, the future supply of sufficient amounts of iridium is very critical. The extraction of iridium through mining cannot be expanded because it exists in very low concentrations and is only extracted as a transitional metal, especially in platinum mining (very high concentration on South Africa). An increase in platinum extraction in the future is not realistic, which is why an increase in the supply of iridium is not to be expected. Other natural deposits of iridium can also be ruled out as a source of increased extraction.

Heat pumps: The main challenge associated with heat pumps, as is the case with electric cars and offshore wind turbines, is the use of permanent magnets made with rare earths, which are often installed in the electric motors of compressors and circulating pumps. However, there is currently no data on what proportion of heat pumps have permanent magnets installed, nor on the proportion of heat pumps that use electromagnets. Further research on this question is required. However, compared to other key technologies and their components, the supply risks associated with heat pumps are significantly lower.

Steel: In the case of steel, the main bottleneck lies in the construction of shaft furnaces for direct reduction (DRI) using hydrogen (or alternatively natural gas), as there are only a few suppliers in this sector. There are also some risks associated with the availability of iron ores with a very high iron content.

In the following section, the raw materials, components and goods examined in this study are categorized according to their degree of criticality. For the raw materials, a distinction is made between raw material extraction and raw material processing.

Criticality in raw material extraction

Very critical: lithium, heavy rare earths and iridium

Of all the technologies examined in depth, the raw materials that are categorized as very critical when it comes to raw material extraction (mining extraction) are lithium (lithium-ion batteries), heavy rare earths (permanent magnets for offshore and electromobility) and iridium (PEM electrolyzers).

- **Lithium:** In the case of lithium, the main challenge lies primarily in the steep increase in global demand (excess demand). The expansion of existing mines and the opening of new mines — or extraction from salt lakes — requires relatively long lead times. The time aspect is thus of decisive significance for the categorization of lithium.

- **Heavy rare earths:** Heavy rare earths such as dysprosium and terbium are currently mined almost exclusively in China and, in much lower amounts, also in Myanmar. This very narrow country concentration is the main reason for this categorization, compounded by the fact that in many (but not all) natural deposits around the world, heavy rare earths occur only in very low concentrations.

- **Iridium:** The mining extraction of iridium is currently 6 to 10 tons per year and cannot be expanded, since it is only extracted as a minor metal, mainly in platinum extraction (very high country concentration on South Africa). Because a future increase in platinum extraction is not realistic, no increase in iridium supply is to be expected. Other natural occurrences of iridium can also be ruled out as a source of increased supply.

Medium critical: nickel, cobalt, graphite and light rare earths

According to the investigations carried out in this study, nickel, cobalt, graphite and light rare earths are categorized as medium critical with regard to raw material extraction (mining extraction). Significant growth in demand can be expected for all of these raw materials in the coming years. However, in contrast to the raw materials assessed as very critical in the section above, there are various reasons (see below) that justify this categorization here as medium critical — despite the great importance of these raw materials:

- **Nickel:** Global mining extraction is relatively widely distributed, although Indonesia is currently in the process of expanding its leading position. The increasing nickel demand can be at least partially mitigated by the growing market share of nickel-free lithium-ion (LFPB) batteries.

- **Cobalt:** The DR Congo is responsible for a very large share of global cobalt mining. However, Indonesia, which will soon become the second largest mining producer, is meeting market demand by expanding extraction (as a minor metal in nickel extraction). In addition, the growth in demand for cobalt is expected to slow down in the medium term due to the increasing use of cobalt-free and low-cobalt lithium-ion batteries.

- **Graphite:** While China plays a very dominant role in mining extraction of natural graphite, the use of synthetic graphite opens up an alternative field here. In addition, the natural graphite reserves are distributed across various countries, making increases in supply possible from these sources.

- **Light rare earths:** Although China is still the country with the largest mining extraction of light rare earths, there has been a clear downward trend in recent years. Light rare earths occur naturally in many countries (Australia, United States, Canada, etc.) and are increasingly being mined in those countries to meet the strong growth in demand.

Moderately critical: manganese, scandium, iron ores in DRI quality

For the purposes of this study, the raw materials manganese and scandium as well as iron ore are categorized as moderately critical in terms of raw material extraction (mining extraction) in DRI quality. There are various reasons for this, which are explained in the respective sections.

Investigations have found the raw materials copper, titanium, gallium, germanium, yttrium and platinum to be not critical, although strategically relevant for the transformation to climate neutrality by 2045. Details can be found in the corresponding chapters of the full version of the study.

Criticality in raw material processing

Very critical: processing of light and heavy rare earths, cobalt, manganese, graphite

For raw material processing, the categorizations scheme into very critical, medium critical and moderately critical differs from that for raw material extraction. The processing of light and heavy rare earths as well as cobalt, manganese and graphite is categorized as very critical. The reasons for the categorization are the same in all cases, namely the very strong to total dominance of China against the background of steep growth in global demand.

Medium critical: processing of polysilicon, lithium and nickel

Raw material processing for polysilicon, lithium and nickel[2] is categorized as medium critical. Although China has a leading position here too, other countries also have relevant market shares.

Criticality in the manufacturing of (sub-) components

Very critical: ingots, wafers, cells for photovoltaics, permanent magnets for offshore wind power and electric motors as well as anode material for lithium-ion batteries in the electromobility sector

In terms of (sub-) component production, the production of ingots, wafers and cells for wafer-based photovoltaics, the production of permanent magnets for wind power and electromobility, as well as the production of anode material (for lithium-ion cells) for electromobility must be categorized as very critical. In all cases, the reason is China's extremely high to overwhelming market power.

Medium critical: Cathode material for lithium-ion batteries

In addition, the production of cathode material (for lithium-ion cells) is categorized as medium critical in terms of (sub-) component production. Although China is the market leader here too, South Korea, Japan and, to a certain degree also the U.S. and the EU play relevant roles as well.

2 At the processing level, lithium refers specifically to lithium carbonate and lithium hydroxide hydrate, and nickel refers to nickel sulfate.

Criticality of goods

At the product level PV modules are categorized as very critical. While China's market share of global production is somewhat lower here than in the upstream stages, and there is currently more production capacity in Europe than is the case for cells, due to the fact that modules manufactured in Europe are largely dependent on imported Chinese PV cells, this study also categorizes module production as very critical. The production of battery cells is also categorized as medium critical due to the strong growth in global demand and China's strong position.

Demand for critical raw materials for Germany to 2045

The study shows that for the seven central key technologies, three raw materials are categorized as very critical (lithium, heavy rare earths, iridium) and four raw materials (nickel, cobalt, graphite, light rare earths) as medium critical. An additional central finding of this study is the quantification of demand in 5-year steps for Germany for these very critical and medium critical raw materials that are necessary for the strategic key technologies up to the year 2045. The projected demand is based on the expansion paths of the "KNDE2045" scenario and the assumptions regarding the development of the concrete technology paths of the individual key technologies. The KNDE2045 scenario was selectively updated to take the expansion of renewable energies and electromobility into account. The "KNDE2045" scenario is based on the number of new automobile registrations calculated in the study "Climate-neutral Germany 2045"; in other words it only takes into account quantities that are necessary to cover domestic demand. The full version of the study provides a comprehensive data overview across these different scenarios.

FIG. 03 **Supply risks for strategic key technologies along the supply chain based on criticality**
The three very critical raw materials (lithium, heavy rare earths, iridium) and the four medium critical raw materials (nickel, cobalt, graphite, light rare earths) will reach their maximum demand in 2030/2035.

Prognos, Oeko-Institut, Wuppertal Institute 2023

For purposes of this study, manganese (lithium-ion batteries) and scandium (high-temperature electrolyzers) are categorized as moderately critical. Copper, titanium, gallium, germanium, yttrium and platinum: According to the investigations that this study is based on, these raw materials are strategically relevant for the transformation to climate neutrality by 2045, but are not critical. The quantification of the iridium demand was based on a reduction in raw material intensity of up to 90 percent compared to today.

Figure 3 clearly shows the quantities that will be needed between now and 2045 to meet the demand for the seven medium critical and very critical key raw materials lithium, cobalt, nickel and graphite (battery raw materials), light rare earths and heavy rare earths earth (permanent magnets in electric vehicles and wind turbines) and iridium (PEM electrolyzers).

All the raw materials shown here will reach their maximum demand in the years 2030 to 2035. The primary reason for this is the rapid expansion of the key technologies over the next ten years. As of 2035, the expansion of most technologies will stagnate (e.g. wafer-based photovoltaics, electric vehicles) or will even start to decline (offshore wind). In addition, increasing material efficiency can reduce the specific raw material demand per installation. This effect is particularly evident in the case of PEM electrolyzers. In contrast to the other technologies presented, the demand for these systems will continue to increase after 2030. However, because of the assumed reduction in the use of raw materials of approximately 90 percent, the overall requirement will decline.

The increase in demand up to the year 2030 underscores the urgent need for action. This applies not only to the seven medium critical and very critical raw materials, but also to their downstream supply chains for the production of lithium-ion batteries, permanent magnets and PEM electrolyzers.

4. Strategies and measures for a resilient transformation to achieve climate neutrality by 2045

Following the previous section's analysis of which supply chain stages present the greatest supply risks for strategic key technologies, this section outlines possible measures that can serve to increase security of supply and strengthen resilience.

This includes in particular the following demand-driven and supply-side measures:

- **Production ramp-up in Europe:** This measure essentially affects all stages of the value chain. Due to the limited geological availability of most critical raw materials, a strengthening of the European mining sector is only possible for a small number of raw materials. This measure therefore applies primarily to downstream stages of the value chain.

- **Diversification of partner countries:** This measure has an effect primarily on supply risks on the raw materials side. The proposals for prioritizing countries are made on the premise that the analysis reveals realistic opportunities for raw material and technology partnerships with Germany and the EU.

  The main criteria for this are the following:

  Reserves: Relevant reserves exist, and ideally production projects are already in operation or are at least in advanced planning stages (time component!).

  Experience: Countries with experience in mining and processing such as Canada, Australia, Brazil, Chile are particularly advantageous, mainly because projects in those countries can be implemented faster, local authorities can apply their experience, and there is higher potential for skilled workers, etc.

  Infrastructure: A sufficient transport infrastructure exists or is being developed: Deep-water ports with corresponding capacities are particularly relevant in this regard. This makes storage facilities near the coast and with good connections to existing road and/or rail infrastructure particularly attractive.

  International relations: The countries in question already have good political relations with Germany and the EU or are at least open to an intensification of economic relations,

  No war zones or crisis regions: These countries do not contain designated war zones or crisis regions.

- **Recycling of critical raw materials:** With some exceptions, for example in the recycling of battery production waste, these measures are only effective in the longer term, since many technologies remain on the market for several decades after the initial ramp-up before they become available for recycling.

- **Reduction of raw material intensity:** This is generally achieved by research and development or through automation and the development of industrial production methods. This measure reduces domestic demand and normally only has an effect in the medium to long term.

- **Alternative technologies:** Shifting to technologies with a lesser need for critical raw materials — for example by using nickel, manganese and cobalt-free LFP batteries.

Below is a summary of the main measures and strategies for a resilient transformation to climate neutrality by 2045 with regard to the identified key technologies. More detailed information on this is available in the full version of this study.

4.1. Photovoltaics

Production ramp-up in Europe: The most important measure in photovoltaics is the development domestic production capacities along the entire supply chain in Europe. According to the Net-Zero Industry Act, at least 40 percent of production capacity is to be produced domestically in Europe by 2030. The major barriers here are the lower production costs (up to 30 percent) in the U.S. and China due to high levels of government subsidies.

Recycling: Significant potential in the area of recycling will only come into play as of 2035 and 2040, as the modules have a long lifecycle and are only available for recycling in the longer term. Recycling processes for the recovery of polysilicon and solar glass is currently still being developed and tested.

Diversification of partner countries: The scale of the diversification potential, on the other hand, is difficult to predict because the possible capacities, for example in the U.S. and India, are only just being developed, and it is likely that efforts will go meeting domestic demand first. Reduction of raw material intensity: The reduction in material intensity, while it has an effect on the raw materials side, does not have an effect on the market power in the downstream supply chain.

Alternative technologies: In addition to wafer-based PV modules, alternative technologies could be used as well. With regard to thin-film modules, however, lower efficiency factors mean a high market share may not be likely. Perovskite or organic cells are still under development and in the short term cannot make a contribution to bolstering resilience.

4.2. Wind power

Keeping production in Europe: Under the Net-Zero Industry Act, a target was set that would require 85 percent of wind turbines to be manufactured in Europe by 2030. In principle, this target is achievable because, in contrast to photovoltaics, there is already a substantial industrial base for wind power in Europe. The most important measure for maintaining a high share of European production is providing support for the upscaling of production facilities, as well as for the ramp-up of capacities, in particular in the capacity range of 12 MW and more for the offshore sector. So far, large offshore wind farms only have a small production capacity; and this needs to be expanded quickly.

In addition, the development of a European supply chain for permanent magnets is key to increasing resilience (see section 4.4 Permanent magnets).

Reduction of raw material intensity and alternative technologies: By increasing the use of gears, it is possible to reduce the demand for rare earths in permanent magnets by approximately 65 percent. However, this also reduces the efficiency of the systems and could lead to higher overall costs, and thus to a greater weakening of European manufacturers, who already have significant cost disadvantages relative to Chinese suppliers.

Recycling: The recycling of rare earths from permanent magnets will only gain relevance from 2035 onwards, due to the lifecycle of the systems.

4.3. Lithium-ion batteries

Production ramp-up in Europe: Under the draft of the Critical Raw Materials Act, ten percent of the raw materials and 40 percent of the processed raw materials are to be covered by European production capacities by 2030. In addition, the EU target for this sector stipulates that by 2030 approximately 90 percent of the required battery cells be manufactured in Europe. In the medium term, mining in Europe is possible, starting around 2026 for lithium (Germany, Finland, France etc.), nickel and cobalt (Finland) and graphite (Norway). For the refining of lithium, capacities in Germany, Poland and Finland will be built up in the medium term starting in 2024. There are already projects underway in Germany and Poland for the production of cathode material. At the gigafactories, large plants for the production of lithium-ion cells are planned, already built or already in operation in numerous EU countries (Hungary, Poland, Germany, France, Sweden, etc.) (35 GWh in total). Taken together, with the realization of a majority of the projects in this sector, a production capacity of >1000 GWh per year could be reached in Europe by 2030.

Diversification of partner countries: For battery raw materials, active materials and battery cells — especially lithium iron phosphate cells (LFP) — achieving a stronger differentiation of supplier countries is necessary and also viable. Existing partnerships with countries such as Chile should be expanded, while new cooperative projects with Australia, Canada, Ghana Namibia and others should be developed.

Recycling: Within the next five to 15 years, the recycling of lithium-ion batteries will start to take on an increasing significance for supply. The groundwork was laid with the new EU Battery Regulation, which is soon to take effect. In order to optimally develop the enormous recycling potential for lithium, cobalt, nickel, etc., massive investments in the entire recycling infrastructure for lithium-ion batteries in Germany and the EU are necessary in the medium and long term, some of which have already begun.

Alternative technologies: For the time being (at least until 2030/2035), lithium-ion batteries will be the dominant technology for traction batteries in electric vehicles. Technological alternatives such as sodium-ion batteries in particular still need time for development and ramp-up. The actual future market potential cannot yet be reliably forecast at this point.

Reduction of raw material intensity: Especially at the product level, an optimized material intensity with regard to critical raw materials for batteries can be achieved through smaller batteries (avoidance of oversized batteries to address the often exaggerated "range anxiety") and by a smaller number vehicles on the road (change in the modal split towards public transport), as well as by the trend toward smaller and lighter vehicles with reduced energy consumption.

4.4. Permanent magnets

Production ramp-up in Europe: The European Raw Materials Alliance has set the ambitious target of 20 percent self-sufficiency in the EU by 2030 for the rapidly growing market for permanent magnets (neodymium iron boron magnets). The main challenges here lie in the existing know-how and cost advantage of Chinese companies, as well as in creating an optimal capacity for businesses and skilled workers in Europe. It is important to develop both of these areas in Europe at a rapid pace. An important step in this area was the launch of an EU-funded investment project in Estonia (magnet factory including upstream production stages).

Diversification of partner countries: With regard to the value chain for permanent magnets, since for the foreseeable future Europe will remain dependent on the import of raw materials, intermediate products and strategic goods, a central measure is the creation of a more diversified supplier country structure. With this in mind, Germany and Europe should commit to furthering intensified joint transformation partnerships (cooperation on technology and raw materials) with suitable countries both in the Global North (especially Canada and Australia) and in the Global South (e.g. Namibia, Malawi, Colombia).

Recycling: Up to 2030, the recycling potential will remain very low, but will increase sharply after 2030, with supply initially coming from end-of-life vehicles and somewhat later from decommissioned wind turbines. The recycling of permanent magnets and rare earths is an area of research and development that still needs to be supported. The first small recycling plants for permanent magnets in the UK and Germany will become operational in 2024. The recycling of permanent magnets is principally a promising option, since 30 percent of the weight of these magnets is made up of rare earth elements, which are again needed for the manufacturing of new magnets. This advantageous elemental concentration is not offered by any of the many natural raw material deposits worldwide.

Alternative technologies: Although electric motors for vehicles that function without permanent magnets are on the market, due to the technological advantages of electric motors that use permanent magnets (lower weight and volume, higher rate of electrical efficiency), at the moment they occupy only a niche. Experts therefore see only moderate potential for alternative electric motors (without permanent magnets) in the medium and long term. In the area of wind turbines, gearless systems that use permanent magnets have clear advantages, especially in the case of particularly large offshore wind farms. As a result, with regard to the use of permanent magnets, and thus the rare earths that are needed for them, no relevant relief can be expected here either . Reduction of raw material intensity: The reduction in the use of heavy rare earths in magnetic alloys has in large part already been explored. Even in the long term, there is only limited further potential in this area.

4.5. Electrolyzers

Reduction of raw material intensity: By far the most important strategic task lies in bringing about a reduction in the specific material requirement for iridium for PEM electrolyzers. Supported by R&D and innovative processes, it is possible to reduce the use of iridium by up to 90 percent.

Production ramp-up in Europe: Based on the targets of RePowerEU, a production capacity for the construction of electrolyzers of around 17.5 GW (relative to hydrogen production and calorific value) can be expected to be achieved by 2025. The low demand that has so far existed for water electrolysis systems has been met in the manufacturing sector and in small series production. In order to meet the rapidly increasing demand, it is essential to develop a gigawatt electrolysis industry with serial production, to achieve a high degree of automation and to make use of economies of scale. The expected increase in production capacity is already becoming evident. It must now be ensured that the announced projects are implemented and further expanded.

Diversification of partner countries: Iridium extraction is highly concentrated on South Africa, followed to a much lesser extent by Zimbabwe and Russia. A diversification of the supplier countries would lead to an only negligible increase in resilience. The main problem is not so much the country concentration, but rather the fact that global extraction is not likely to increase. Iridium is only obtained as a by-product (in very low concentrations) of platinum extraction.

Recycling: Recycling of key raw materials from used electrolyzers (in particular iridium and platinum as well as titanium) only offers a viable perspective in the long run, albeit one that can already be initiated today. Research efforts into this field are already underway in Germany.

Alternative technologies: Alkaline electrolyzers (AEL) as a possible alternative to PEM electrolyzers currently have a market share of 70 percent and do not use any critical raw materials such as iridium. Due to their relatively low efficiency, however, they require more electricity and can be operated less flexibly. Such flexibility is particularly needed for electricity systems that use a very high proportion of renewable energy sources. Additional alternatives would be high-temperature electrolyzers (HTEL) or anion exchange membrane electrolyzers (AEM). These technologies, however, are currently only at the pilot stage, and future market penetration is still uncertain. HTEL also require scandium, 75 percent of which has so far been mined in China. Here, however, diversification of supply to include countries such as the United States, Canada, but also EU countries (Finland, Sweden, Greece) is a possibility.

4.6. Heat pumps

Production ramp-up and keeping production in Europe: Today, production capacity in Europe is already at

19 GW. Based on the targets of the Net-Zero Industry Act, at least 85 percent of newly installed systems are to be manufactured in Europe by 2030. This corresponds to a production capacity of around 31 GW and a necessary increase of 50 percent relative to today. Manufacturers expect an overall significant market growth in Europe and are expanding their capacities accordingly. In order to cover this ramp-up as well as the necessary investments, there must be reliable framework conditions in place for bringing about a reduction of greenhouse gases in the building sector. Decisive factors for Germany's further perspective up to the year 2030 are the German Energy Act for Buildings (Gebäudeenergiegesetz, GEG) and an increase in CO_2 pricing that is predictable for all stakeholders.

Alternative technologies, diversification: It is possible to use electromagnets (induction motors) instead of permanent magnets for motors of the compressors and circulation pumps. Investigations are still needed into how further technical development can offset the disadvantages of induction motors (partially lower efficiency, somewhat higher sound volume). To date, the topic of permanent magnets in heat pumps has hardly been scientifically studied.

In addition, the development of a European supply chain for permanent magnets is key to increasing resilience (see section 4.4 Permanent magnets).

4.7. Steel

Production ramp-up and keeping production in Europe: In light of the impending supply bottlenecks in plant construction, speed is of the essence in constructing shaft furnaces for direct reduction with hydrogen (DRI plants) in Germany. Political stakeholders can support this development in particular through foresighted infrastructure expansion and financial support, as a supplement to the Carbon Border Adjustment Mechanism (CBAM), as well as by supporting the ramp-up of a lead market for green steel.

Recycling: In the steel sector as well, a strengthened supply of domestic secondary material is the best insurance against import dependencies. In order to achieve this, however, scrap sorting must be greatly improved, especially in the automotive sector.

Diversification of partner countries: Germany should also have an interest in a secure DRI supply, also through imports. This could be supported by measures to promote the development of supply relationships or liquid markets, for example through credit protections. Fixed supply contracts for green DRI with Sweden are one possibility. In the medium term, opportunities for diversification should arise as soon as projects have made progress on the Iberian Peninsula, in Australia, Brazil and Africa. Liquid global markets for green DRI would be preferable from an efficiency standpoint, although it is not clear whether a robust development in this area would be possible in light of the protectionism that is particularly virulent in the steel sector.

4.8. Conclusion

For all prioritized key technologies, it was possible to identify relevant measures from the following five areas to achieve an in increase in resilience. The most important examples are briefly summarized below.

Production ramp-up in Europe

Shifting the value chain back to Germany and Europe, or developing a new value chain here, is essential for large parts of the PV value chain. Particular efforts should go toward strengthening the market shares for the production stages of ingots, wafers, PV cells and PV modules for the market-leading technology of wafer-based photovoltaics. Europe currently has very little production capacity in these areas, and a significant increase in production capacity in the EU by 2030 is of strategic importance with an aim to increasing resilience and reducing dependencies.

With regard to the value chain for lithium-ion batteries (electromobility), the necessary development of a European value chain through financing (from EU, German government, etc.) of "gigafactories" and upstream stages (lithium refineries, cathode material production etc.) has already begun. Despite current challenges such as that posed by the United States' Inflation Reduction Act, these activities must be continued in a consistent manner and expanded to include raw materials extraction within Germany and the EU (the focus here is primarily on lithium).

Likewise, groundwork must be laid for building and bolstering relevant production capacities in Europe for the value chain of permanent magnets (processing of rare earths, extraction of rare earth metals and extraction of neodymium iron boron magnets) as well as for electrolyzers and DRI steel.

Diversification of partner countries

The diversification of supplier countries (outside of the EU), especially with regard to the supply of raw materials and intermediate products, is a second important pillar of building resilience.[3] Of absolutely importance is, on the one hand, the strengthening of economic ties with established partners such as Chile (lithium, copper), Canada (lithium, nickel, rare earths), Australia (lithium, rare earths, nickel, cobalt), Brazil (graphite, lithium, manganese). On the other hand, with an aim to further expanding the diversification of supplier countries, the development of new raw material and technology partnerships with countries in the Global South is highly recommended. Examples of countries that could enter into possible future cooperation projects are Ghana (lithium), Indonesia (nickel, cobalt), Namibia (rare earths, lithium), Malawi (rare earths, incl. heavy rare earths) and Colombia (rare earths, nickel). The table above shows examples of (potential) countries that supply key raw materials. The table makes no claim to completeness. Furthermore, it is important to note that, following Indonesia's example, more and more countries will not export non-processed raw materials. This allows the respective countries to increase the share of added value in their own country by carrying out the further processing stages of raw materials themselves. Here it is important to develop fair partnership models in the sense of true transformation partnerships that are developed "at eye level", i.e. on equal terms.

Recycling

Recycling, as the third important pillar for strengthening resilience, is initially relevant in terms of timeline for the recovery of battery raw materials such as lithium, cobalt, nickel and copper. The first recycling plants have begun operations in Germany and Europe, and the upcoming adoption of the new EU Battery Regulation will lay out an ambitious regulatory framework. Efforts must now be redoubled to continue necessary measures to increase recycling activities in order to exploit the large recycling potentials that will emerge starting in 2030 and beyond.

Recycling is also of major strategic relevance with regard to permanent magnets (rare earths). In this area, however, more effort has to be devoted to research and development and towards advancing the corresponding technological innovations for the recycling processes in order to tap into the full recycling potential. The EC's proposal for the Critical Raw Materials Act and the revision of the EU End-of-Life Vehicle Directive also creates important regulatory framework conditions that must be supported. The recycling of PV modules and materials from electrolyzers (titanium, iridium, platinum) is also an option, which however will only gain relevance as of 2035.

Reduction of raw material intensity

Innovations in the area of reducing the raw material intensity by increasing the material efficiency of specific

3 General criteria for prioritizing supplier countries outside the EU are listed at the beginning of this main chapter.

TABLE 01 **Potential supplier countries for key raw materials for the transformation to climate neutrality**
The table includes established producers such as Chile for lithium as well as potential new countries for future resource and technology partnerships such as Namibia for lithium and rare earths

Potential supplier countries for key raw materials	Raw materials	Comments
Australia	Lithium, light and heavy rare earths, nickel, cobalt	Extensive lithium extraction and mining of rare earths already underway
Brazil	Graphite, lithium, manganese	Mining or exploitation (lithium) of tailings already underway
Chile	Lithium, copper	Extensive lithium and copper mining, lithium extraction is to be expanded already underway
Ghana	Lithium	No extraction yet, mining project is planned
Indonesia	Copper, nickel, cobalt	In particular, existing nickel and cobalt extraction is to be robustly expanded.
Canada	Lithium, nickel, cobalt, rare earths	Lithium extraction, which so far has been very low, is to be expanded. Rare earth mining projects in planning and development stages.
Colombia	Rare earths, nickel	Expansion of nickel extraction planned, reserves for rare earths
Malawi	Light and heavy earths	No extraction yet, mining project is planned
Madagascar	Graphite	Existing mining extraction
Mozambique	Graphite	Existing mining extraction
Namibia	Light and heavy earths, lithium	No extraction to date; projects in planning and development stages.
South Africa	Manganese, iridium, platinum	Most important mining producer for the three raw materials
Zimbabwe	Iridium, platinum	Existing mining; however, significantly lower extraction compared to South Africa

SOURCE Own compilation Oeko-Institut based on (U.S. Geological Survey, 2023)

Oeko-Institut, 2023

components are particularly relevant for the future expansion of production of PEM electrolyzers. A significant reduction in the specific iridium requirement of PEM electrolyzers is an absolute prerequisite for the successful mass production of this technology, which is crucial for the development of a global hydrogen economy. In the area of permanent magnets, there is at least moderate potential for reducing the content of heavy rare earths through innovations in magnet production. Heavy rare earths are categorized as very critical for the purposes of this study.

Alternative technologies

Alternative technologies are emerging within the lithium-ion battery product family or are have already become ready for the market. Notable in this context is the expanded use of low-cobalt NMC811 batteries on the one hand, and above all, of nickel, cobalt and manganese-free LFP batteries on the other. Other alternatives that are currently under development and may become relevant after 2030 are solid-state batteries or sodium-ion batteries.

5. Policy Recommendations

Based on the investigations into the demand and the supply side for the technologies that are particularly important in the context of this study, the project team has identified the following possible strategies and instruments for increasing the resilience of the relevant supply chains. An in-depth examination of the individual instruments was beyond the scope of this study. The following initial recommendations are instead intended to define a framework in which the possible effectiveness and priority applicability can be further explored in subsequent studies, with the aim of achieving a robust strengthening of the resilience of important supply chains for the transformation.

Introduce comprehensive resilience monitoring

For all of the value and supply chains defined in this study as priorities (PV, wind power, permanent magnets, batteries for electromobility, electrolyzers, DRI steel and heat pumps), it is advisable to introduce resilience monitoring, which at regular intervals, once a year for example, can provide political and economic decision-makers with relevant information on strategic value chains. It is important that the entirety of the respective supply chains be analyzed with regard to their vulnerabilities and resilience, that this is carried out from both a German and a European perspective and that the information is quantifiably supported as far as possible. Resilience monitoring requires its own institutional anchoring.

Create stable sales markets for transformative key technologies

The creation of a reliable domestic market in Germany and the EU is essential for all key technologies, also from the perspective of resilience. Various individual instruments are of relevance to achieve this. This includes the creation of attractive framework conditions for markets, i.e. regulatory measures (regulatory law, CO_2 pricing, infrastructure expansion and subsidies) that are as stable and predictable as possible, the support of green lead markets, a foresighted effort to secure skilled workers, expedited planning and approval processes, the reduction of burdensome bureaucracy as well as the development and continuation of clear export strategies (e.g. in the field of renewable energies in offshore wind power).

Establish resilient content rules

Resilient content entails the establishing of standards and qualities such as specifications regarding the carbon footprint or environmentally and socially responsible supply chains. The new EU Battery Regulation, for example, already includes provisions for specific target years. The instrument could be used to limit the import of goods that are produced under low environmental and social standards.

More in-depth investigations into this relatively sensitive instrument are necessary with regard to the value chains that have been categorized as priorities. Conformity with WTO rules, for example, is relevant. The criterion could be used in different ways, for example by way of bonuses in tender procedures or feed-in tariffs (based on the staggered model of the Inflation Reduction Act), or also as a qualitative criterion in corresponding auctions.

In the area of offshore wind power, resilient content specifications could help to establish a long-term perspective for production commissioning, in particular for European-coordinated expansion paths. Tenders should also be designed to prioritize the use of European technology. This could also be an important contribution to designing the necessary export strategy.

Facilitate purchasing groups for strategic raw materials and goods

Bundled purchasing groups could strengthen the position of German and European companies on the global market thanks to their added purchasing power. Today, antitrust law can prevent the formation of such purchasing groups. In the interest of strengthening supply chains and companies, the possibility of adjusting antitrust law should be examined.

Strong representation of domestic business location policy in the area of strategic raw materials and goods

The basic premise of this overarching supply-side strategy is that creating resilience insurance for future transformations comes at a cost. For strategic supply chains, which are indispensable for a resilient and future-proof economy, domestic market players will have to receive robust support through additional financial means during a transitional period, to protect them from structurally unfair competition coming from outside the EU (market advantages as a result of various state subsidies, taxes and levies, undercutting of environmental and social standards, etc.). This support should continue until a truly level playing field is reached in this area.

Initially, investment subsidies (CAPEX) should be taken into consideration. Well-known examples are IPCEI projects, i.e. investments classified by the EU as "Important Projects of Common European Interest", which are particularly eligible to receive support. The determination of eligibility for funding for the establishment of a business location should be based not only on regional criterial, but also and in particular on resilience factors.

An addition supply-side instrument used by the EU is the "Just Transition Fund", which provides special funding for investment projects for regions particularly affected by transformation. A current example is the funding of a magnet factory in Estonia (construction incl. preliminary stages have recently begun) within the framework of the Just Transition Fund. The Lusatia region, which was particularly affected by the phase-out of coal production, would certainly be a prime example of a region that can present persuasive arguments for receiving corresponding investments.

In addition to CAPEX funding, however, OPEX funding that is at least limited in time may also be necessary. This instrument should take into account all energy-intensive productions for priority value chains that have massive competitive disadvantages in terms of operating costs compared to competitors outside of Europe. This may be very relevant, for example, with regard to battery cell factories, plants for the production of permanent magnets and also certain parts of the value chain for photovoltaics and the production of green steel. One component of such an OPEX funding could be an industrial electricity price that is set for a limited time period, or limited to certain industries or processes.

In principle, a business location policy that is financially supported as outlined above can help strengthen value chains in Europe and also contribute to a more efficient domestic production by giving impetus to economies of scale.

Expand and strengthen transformation partnerships on equal terms

For a number of products such as lithium-ion batteries, permanent magnets and electrolyzers, analyses have shown how important it is to have more diversified supply relationships with countries outside the EU. Within the context of this study, general criteria have been formulated for a pre-selection of countries in both the Global North and the Global South. These partnerships should by no means only be limited to the procurement of raw materials, but should instead also focus on intermediate products and end products. The establishment of so-called transformation partnerships on equal terms ("at eye level") is key to ensuring that the diversification strategy is also successful in the long term. Countries of the Global South (e.g., Indonesia, Namibia) in particular will make future economic cooperation dependent on a greater participation in the value chain.

Germany should definitely combine these new partnerships on raw materials and technology with educational and research collaborations that give substance to these partnerships and ensure that they take place on equal terms. One of the recommendations arising from this study is to undertake more in-depth investigations of the proposed countries over the next few months in order to determine their specific suitability for such partnerships.

Early-stage capacity building in the recycling industry

For a number of strategic raw materials such as lithium, nickel, cobalt and copper from batteries, rare earths from permanent magnets, the end-of-life material flows that will increase in the future (e.g. from de-registered vehicles, decommissioned wind turbines) represent an attractive domestic source of supply for strategic raw materials in the medium and long term. The European metals recycling industry operates at a world-class level in some areas (e.g. copper and precious metals). This optimal starting point must be bolstered with suitable regulatory instruments to support "new" or currently growing recycling infrastructures (such as for lithium-ion batteries, permanent magnets, and later also for PV modules and electrolyzers). The EU Battery Regulation, which will soon come into force, has paved the way with collection targets, material-specific

end-of-life recycling quotas (for lithium, etc.) as well as recycled content specifications for batteries that are to enter the market in the future. It is now of paramount importance to robustly implement enforcement in all EU countries over the next few years in order to achieve the ambitious goals that have been set.

The draft law of the Critical Raw Materials Act has set important parameters for the future recycling of permanent magnets and rare earths in the EU. Another important set of rules that is currently in revision process is the EU End-of-Life Vehicle Directive. One of the specific areas of focus relates to specifications for the dismantling and processing of electric motors (permanent magnets). Other accompanying instruments to support recycling within the EU are design requirements (see EU Eco-Design Directive), R&D funding for new innovative recycling processes or even export restrictions for strategic (intermediate) products from recycling processes. A current example is the related discussion regarding restrictions on the possible export of the valuable "black mass", an intermediate product that comes from the recycling of lithium-ion batteries.

Even if recycling will only supply Europe with relevant amounts of strategic raw materials in the medium term (as of 2030) or long term (as of 2035), the instruments for tapping into this potential must be launched within the next three years.

The transformation to climate neutrality requires a rapid and decisive investment and modernization program in Germany and the EU. A resilient supply with necessary raw materials and strategic goods is an elementary prerequisite to be successful. In this context, new geopolitical challenges must be taken into account in such a way that Europe and Germany do not become susceptible to blackmail and the necessary political freedom for sovereign action is preserved.

The study of the Climate Neutrality Foundation identifies crucial weak points for strategically important transformation industries along the entire value creation and supply chain. It provides answers for politics, business and society on how to increase resilience to exogenous shocks.

The Climate Neutrality Foundation was established to develop robust cross-sector strategies for a climate-neutral and -fair Germany. Based on sound research, the foundation aims to inform and advise — beyond individual interests.

On behalf of the

Climate Neutrality Foundation

Under this QR code, the publication "Securing Germany's Sovereignty – Resilient supply chains for the transformation to climate neutrality by 2045" as well as further studies by the Climate Neutrality Foundation are available online for download.