imports of many mineral resources that are essential not just for its traditional industries but also for the energy transition and digitalisation. The danger of the formation of new geopolitical blocks amid Germany's substantial economic connections with the US and China makes it necessary to prepare for both economic and geopolitical shocks and secure the supply of raw materials to be able to achieve the intended climate and digitalisation targets.

A study commissioned by KfW Research examined the significance of raw materials for value added in Germany and the current situation around the supply of raw materials. The analysis was conducted by IW Consult and Fraunhofer ISI and focused on three selected minerals – copper, lithium and the group of rare earths –, each of which are of key relevance for digital and climate technologies. The various dependencies and supply risks for these raw materials result in a number of implications for the private sector and government to improve raw materials supply security. After all, high vulnerability is not set in stone and can be reduced with various approaches.

Raw materials supply in times of polycrisis and in the historic context

The Ukraine war and COVID-19 pandemic have prompted the EU and Germany to pay more attention to the issue of making value chains resilient to supply shocks and bottlenecks. Country risks play a relevant role for the availability of mineral resources. Thus, the countries that produce those minerals can limit their exports – be it for economic reasons to bolster downstream processing stages or out of geoeconomic considerations. One prominent example is the conflict between China and Japan over rare earths in the year 2010. The OECD has found that the imposition of export restrictions including export taxes on critical raw materials has increased more than fivefold in the past ten years.[2] Of the three minerals under review here, lithium is subject to the fewest and copper to the most restrictions. In addition, there may be restrictions on the export of technologies used in the extraction and processing of raw materials, with the most recent example being China's announcement of export bans on rare earth production technologies.[3] The security of Germany's raw materials supplies was an issue even well before the COVID-19 crisis and the Ukraine war. The oil crises of the 1970s also shifted the focus on other resource dependencies in a similar way as the issue of energy security in the wake of the Ukraine war.[4] Germany's high import dependency was determined for various raw materials, even if lithium and rare earths did not yet play a role at the time. The first raw materials strategy of the Federal Government was then presented in 2010. It aims at 'Securing a sustainable raw materials supply of non-energy mineral resources for Germany'.[5]

A close look at the entire value chain is warranted

Looking at raw materials security, the focus usually lies on ensuring supplies and, hence, on import risks. The entire raw materials value chain from extraction to recycling and recovery plays a role here. Therefore, raw materials that have already been processed into goods must also be taken into account.[6] The relevant analyses concentrate on determining import dependency and supplier concentration of primary raw materials and early processing stages, in part supplemented by the economic significance of the raw materials or their use in key technologies for the dual transformation.[7] The EU's methodology for determining criticality considers, for example, the economic significance measured by the contribution which the raw materials make to value added in the sector of final consumption in combination with economic substitution possibilities.[8] For the EU, light rare earths have the highest and lithium the lowest economic significance of the minerals under consideration here. All three minerals, however, by far exceed the threshold above which they are deemed critical for this dimension.[9]

Should supply bottlenecks occur, however, this would affect the entire value chain of the raw material up to the final products. The COVID-19 crisis illustrated that supply shocks at the beginning of value chains can continue to industries being near the final consumers.[10] Ultimately, raw materials are used primarily as production inputs, and their absence potentially has systemic consequences.[11] This also distinguishes them significantly from energy resources as they do not influence the use of existing goods, as in the case of oil, for example, but their production.[12]

The present analysis explores not just the supply-side risks and raw material imports but the value added and jobs in Germany that rely on the production of goods containing copper, lithium and rare earths (see Box 1).

Box 1: The raw materials value chain disentangled

Raw materials and refined products are used at the beginning of value chains or later added to processing stages leading to finished capital goods and consumer goods. Their absence would impact on all downstream processing stages with negative effects on the value added there and the necessary labour employed. That makes it necessary to examine all stages of goods and value creation in which the raw material or raw material-containing input is processed.

The value chain of a raw material comprises the raw material itself, initial processing stages and inputs up to finished consumer and capital goods. The corresponding observations are based on substance flow analyses used to identify material flows (see Figure 1).[13] With this method, the study commissioned by KfW Research classified goods as being dependent on the three minerals copper, lithium or rare earths under review as soon as the corresponding mineral is processed in a product.[14] The volume of minerals contained in the goods is unimportant because even small quantities may be essential for their manufacture.

The supply risk is determined on the basis of country concentration and average country risk. However, the country of raw material production and the registered office or office of the most influential shareholder are not always identical, which may alter the assessment of country risks.[15] Furthermore, the analysis focuses on the country risk posed by the direct suppliers. As a result, the country risk tends to be underestimated as soon as these are other EU countries that have no raw materials production of their own.

In some sectors, gross value added relies on all three minerals under consideration, while other sectors have a more specific dependency:

– The largest segment of the manufacturing sector as measured by gross value added, automotive construction, uses all three minerals extensively to create value. Value added in the automotive and vehicle parts industry is substantially dependent on copper (74% of gross value added by the industry), rare earths (65%) and lithium (45%).
– Gross value added in the areas of electrical equipment, electronic and optical products and chemicals, too, relies on all three minerals, although the share of lithium-dependent value added is much smaller here than for copper and rare earths. The chemicals industry has very little dependency on any of the three minerals. The value created by these three industries is relatively resource-dependent, and combined they make up a substantial 21% of gross value added by manufacturing in Germany.[19]
– Mechanical engineering and metals processing, the second and third largest economic sectors, are less dependent on the minerals under consideration. Products containing copper or rare earths, however, play a role in value added in mechanical engineering as well as metal production and processing. Mechanical engineering relies on products containing copper to a significant extent.
– The production of furniture and other goods – which also includes the manufacture of medical and dental equipment and materials and seats for aircraft and motor vehicles – is highly dependent on rare earths. Goods containing lithium as well as products containing rare earths play a certain role in value creation in the area of rubber and plastic goods. In glassware and ceramics, rare earths tend to be more relevant than lithium.

The size and dependency of the sectors on raw materials is also reflected in the composition of raw materials-dependent value added and employment by sector, with the manufacture of motor vehicles and parts accounting for the highest share.

Imports containing copper, lithium and rare earths make up half of the value of goods produced with these minerals in Germany

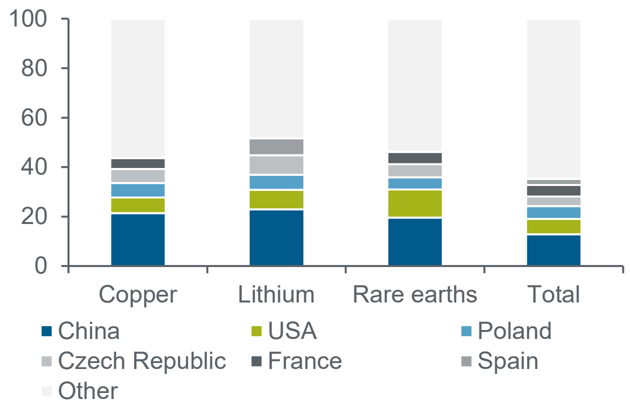
In analysing the importance of raw materials for Germany's economy, imports of primary raw materials and raw material products at the early processing stages are relevant, but also imports of further processed goods. Hence, the level of dependency at all processing stages matters. After all, it is not only about production but about meeting final demand with capital goods and consumer goods. Even in a very open economy such as Germany, which had a ratio of imports to nominal GDP of 49% in 2022[20], production value exceeds the value of imports of resource-dependent goods as well. Thus, across all stages of value added, the ratio of raw materials-containing imports to raw materials-dependent production value[21] is around 1 to 2. For lithium and rare earths, Germany is 100% dependent on imports in the early processing stages.[22] The EU is also 100% dependent on imports of lithium and rare earths and 44% on copper at the level of mining output.[23]

The significant differences in import dependency at various stages of processing are due to the value creation process and import pattern. Thus, the value of further processed imported goods such as permanent magnets, solar panels and batteries is much higher than the value of the critical primary resources contained in them and the early processing stages.[24] First of all, this reflects the fact that value is added in further processed goods and second, that the EU imports only relatively few primary raw materials for further processing within the economic area, tending instead to import products that have already been processed further to meet demand.

The main countries of origin of imports containing copper, lithium and rare earths reflect Germany's import relations overall – with the exception of the role of the Netherlands[25](see Figure 3). The highest shares of goods containing copper, lithium and rare earths are imported from China and the US. At the same time, these are the most important individual countries for goods imports for Germany overall. Within Europe, relatively close links also exist with the direct neighbours France, Poland and the Czech Republic, both for raw materials-dependent imports and in general. Spain is among the five most important countries of origin for goods containing lithium imported into Germany. The country shares for resource-dependent imports tend to be higher than the overall import shares, which suggests a certain degree of specialisation and division of labour.

Figure 3: The five main countries for imports of goods containing raw materials

Shares in import value in EUR in per cent, 2022



The category 'Total' refers to the imports of goods containing and not containing raw materials combined.

Sources: Bähr, C. et al. (2024), Kritisch für die Wertschöpfung – Rohstoffabhängigkeit der deutschen Wirtschaft (*Critical for value added – raw materials dependency of German industry* – our title translation, in German), study for KfW Group, prepared by IW Consult and the Fraunhofer Institute for Systems and Innovation Research, Federal Statistical Office, KfW Research.

Almost one third of the value of imports containing lithium and just under one fifth of imports containing copper and rare earths are classified as at-risk

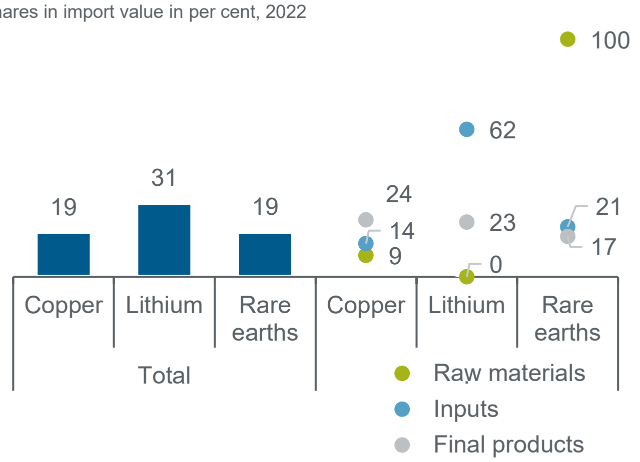
The substantial volume of imports containing copper, lithium and rare earths in relation to production value and the significant shares of the main import countries make it expedient to analyse the supply-side risks for imports containing raw materials across all stages of the value chain (see Box 2). Depending on the degree of completion of the imported goods, other areas of the economy are potentially affected if a supply-side risk materialises. Missing inputs such as circuit boards and semiconductor elements affect production and value creation in Germany itself and can disrupt the entire value chain through multiplier effects. A shortage of capital goods would directly affect final demand and future production potential if they are not substituted over an extended period of time. A lack of consumer goods is also relevant to final demand. Consumer goods also include pharmaceutical goods, and a shortage of these can directly impact on supply security in healthcare.

Nearly one third of the value of imports containing lithium is deemed to be at risk (Figure 4). This is mainly due to the high concentration on a few supplier countries, while the average country risk is deemed moderate. For copper and rare earths, 19% of the import value is at risk. For these two minerals, too, the classification is a result of the concentration of import countries, whereas the average country risk is moderate in both cases.

A breakdown by minerals, inputs and final products shows different patterns of at-risk input value for the three minerals. For copper the import share at risk increases along the value chain. For lithium it is mainly the inputs and for rare earths it is the mineral imports themselves that are classified as at-risk. But for these two minerals, too, 23% and 17% of the import value of the final products remains classified as vulnerable.

Figure 4: At-risk imports of goods containing raw materials

Shares in import value in per cent, 2022



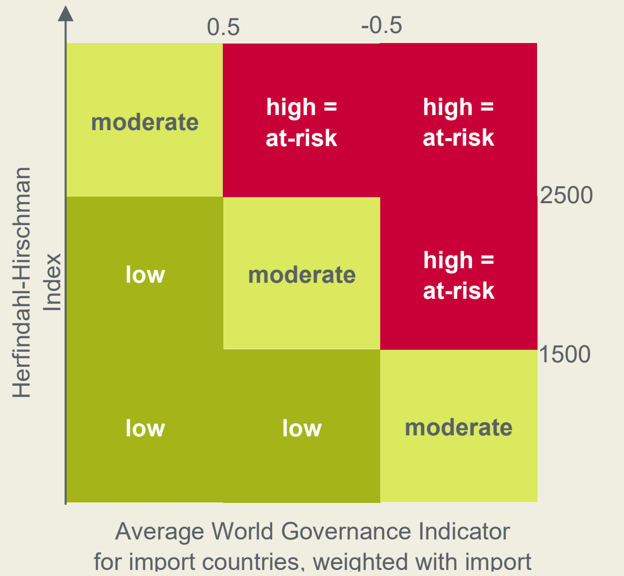
Source: Bähr, C. et al. (2024), Kritisch für die Wertschöpfung – Rohstoffabhängigkeit der deutschen Wirtschaft (*Critical for value added – German industry's raw materials dependency* – our title translation, in German), study for KfW Bankengruppe, prepared by IW Consult and the Fraunhofer Institute for Systems and Innovation Research. Rendition: KfW Research.

Box 2: Identifying vulnerable imports

Within the present study, the at-risk imports were identified on the basis of market concentration and average country risk in accordance with the Worldwide Governance Indicator (see Figure 5). Where market concentration or the average country risk turn out high and the respective other indicator is at least moderate, the input value of the good is classified as at-risk, in other words, fraught with risk.

Figure 5: Classification grid for vulnerable / at-risk imports

Country concentration measured by the Herfindahl-Hirschmann index, Country risk measured by the average Worldwide Governance Indicator



Source: Bähr, C. et al. (2024), Kritisch für die Wertschöpfung – Rohstoffabhängigkeit der deutschen Wirtschaft (*Critical for value added – German industry's raw materials dependency* – our title translation, in German), study for KfW Group, prepared by IW Consult and the Fraunhofer Institute for Systems and Innovation Research, illustration: KfW Research.

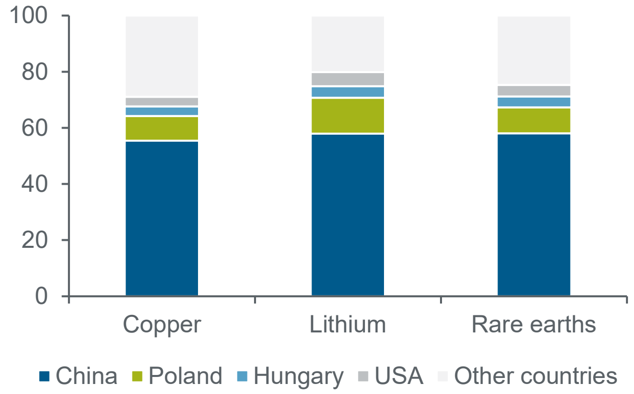
As risk is assessed purely on the basis of market concentration and average country risk in accordance with the World Governance Indicator (WGI), there are limits to how the results can be interpreted. On the one hand, a concentration on few source countries tends to be uncritical if other potential supplier countries exist with which trade relations can be initiated at short notice. On the other hand, the WGI is only one approach to assessing country risk and, thus, the probability of supply bottlenecks. For example, an increase in protectionist tendencies can also jeopardise supplier relations even if the country risk is classified as low on the WGI.

China has great significance for at-risk imports of goods containing minerals

Vulnerable imports are predominantly procured from China, which supplies Germany with 55% of imported copper-containing goods and 58% of goods containing lithium and rare earths (see Figure 6). Poland also provides a considerable proportion of vulnerable imports across all stages of the value chain.

Figure 6: Countries of origin of vulnerable imports

Shares of vulnerable import value in per cent, 2022



Source: Bähr, C. et al. (2024), Kritisch für die Wertschöpfung – Rohstoffabhängigkeit der deutschen Wirtschaft (*Critical for value added – German industry's raw materials dependency* – our title translation, in German), study for KfW Bankengruppe, prepared by IW Consult and the Fraunhofer Institute for Systems and Innovation Research. Illustration: KfW Research.

China's important role for at-risk imports becomes even clearer when we consider the share of imports of goods classified as vulnerable sourced from China:

- For copper-containing goods imports, China is the most important country of origin for 83% of vulnerable goods and for 86% of the vulnerable import value. For example, 61% of padlocks, 86% of data devices and 68% of vacuum cleaners come from China.
- China is the most important country of origin for around two thirds of the vulnerable groups of goods containing lithium and 85% of their import value. The country supplies 49% of lithium-ion batteries and 87% of mobile phones.
- China is the main source country for almost 80% of goods classified as vulnerable and for 89% of their import value. For example, 82% of rare earth metals, 55% of glassware made from glass ceramics and 84% of permanent magnets are procured from China.

China's great importance for imports that rely on copper, lithium and rare earths is also reflected in Germany's economic dependencies on China overall, as analysed in studies on the economic dependencies of Germany and the EU beyond raw materials:

- Flach et al. (2021) concluded that around 3% of the industrial goods which Germany relies upon come from China, spread across a range of sectors from chemicals to textiles.[26]
- Zenglein (2020) identified 103 product categories for which the EU is critically dependent on Chinese imports, particularly in the areas of electronics, chemicals, minerals / metals and pharmaceuticals / medicine.[27]
- Sandkamp et al. (2023) have determined that for 127 of more than 6,000 products examined, China and Taiwan together account for more than 80% of German imports.[28] These are primarily technical devices such as laptops, mobile telephones and computer units, where China's world market share is around 75%. However, textile products such as particle-filtering half-masks, bicycle parts and organic chemicals, medicines and vitamins, minerals including rare earths are mainly procured from China.
- Arjona et al. (2023) have concluded that China is the main country of origin for 64 of the 204 goods which the EU relies upon in critical ecosystems (58% of their import value). Irrespective of country of origin, goods on which a strategic dependency exists are allocated to the areas of chemical and related industries, mechanical devices and electrical equipment, non-precious metals and their products, mineral products and precision instruments and medical equipment.[29]

Preventing potential supply shortages or reducing risks

For one thing, shortages of primary raw materials and raw material-containing imports can emerge in the short run when unexpected events such as strikes, natural disasters, pandemics or geopolitical events occur. They mainly represent exogenous supply shocks for Germany and can involve one or more supplier countries of raw materials at once. Nonetheless, risk-mitigating factors can be identified. These include, for example, diversifying import countries, domestically producing primary raw materials and sourcing and further processing secondary raw materials, and stockpiling.

For another, shortages can emerge over the long term when global demand for raw materials grows faster than their supply – all other things being equal. If the market price is unable to balance supply and demand, supply must be rationed. In that case, a precautionary increase in supply – whether for primary raw materials, in the form of secondary raw materials or by substitution – would reduce the probability of such a scenario occurring. Regulatory and long-term industrial policy developments in the countries where the materials are extracted and refined also play a role. Reducing demand is also helpful to prevent supply shortages. Box 3 discusses the development of supply and demand for copper, lithium and rare earths. In the following, we will take a closer look at various aspects of the risk profiles of the three minerals such as country concentration and longer-term demand trends as well as risk-mitigating factors such as substitution options.

In the study commissioned by KfW Research, the statements on the short- and longer-term risks to supply and potential impacts on value creation in Germany are based on quantitative analyses and supplemented by a qualitative analysis on the basis of structured interviews with market stakeholders from the areas of copper, lithium and rare earths.

Box 3: Level of international climate ambition is crucial in determining global demand trends.

Copper, lithium and rare earths are of crucial strategic importance for the green transformation and the expansion of digitalisation. The expected development of global demand closely correlates with the respective level of ambition on climate action and sustainability.[30] Nonetheless, demand for copper is also heavily influenced by the business cycle through manufacturing and construction activities.

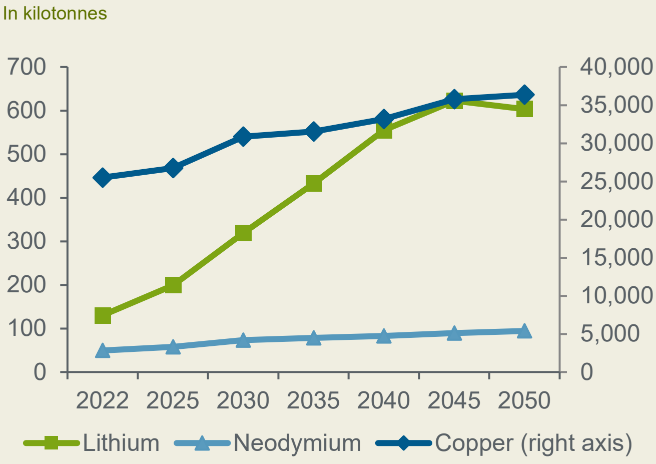
The IEA predicts demand for copper to grow at a rate of 24% from 2022 to 2035 – assuming existing and announced policies are implemented as intended (see Figure 7).[31] The main drivers are the manufacture of electric vehicles and expansion of electricity grids in connection with the development of renewables. Demand for neodymium, which belongs to the group of light rare earths and is used to make magnets, is expected to soar by 58% by 2035. Demand for lithium, the 'white gold' of electric mobility, is even expected to skyrocket by 230%.

Demand predictions vary widely for the three minerals under review. For **copper** it is uncertain whether supply will be able to meet the expected growth in demand in the medium term. Not enough high-quality large-scale projects are currently under preparation. Furthermore, incremental costs are rising as existing mining companies in Chile face decreasing ore content in deposits and water scarcity. The IEA therefore sees potential for the copper market to flip to a supply deficit after 2024.

In order to drive the expansion of **lithium production**, it will be necessary to identify new production locations. In the five years leading up to 2022, annual lithium extraction was massively expanded from just under 50,000 tonnes to 130,000 tonnes of lithium content.[32] Indeed, the supply of lithium is currently even growing faster than demand, a trend that has led to short- to medium-term excess capacity in the course of 2023 (particularly for Chinese lithium-ion batteries) and a sharp drop in prices.[33] Given that demand is forecast to rise dramatically in the long term, however, Schmidt (2023) predicts a significant supply deficit with negative market coverage for the European market in 2023. This would also be the case in a scenario in which the supply of lithium from recycling sources rises significantly.[34]

To meet demand for **rare earths** in the future, the main priority will be to set up alternative production locations outside China based on broad availability, with a focus on the US, Australia, Finland, Sweden and the Baltic states in Europe. But even expanding extraction in China has its limits. Chinese consumption has already exceeded the allocated production quotas in the past.[35] The resulting market deficit is being covered by undocumented extraction, including imports from Myanmar. Expanding global production is being challenged by China's dominant position in the separation of the individual elements.[36]

Figure 7: Estimated growth in global demand for selected minerals by 2035



Note: Stated-policy scenario refers to existing and announced policy measures up to September 2022.

Sources: IEA, KfW Research

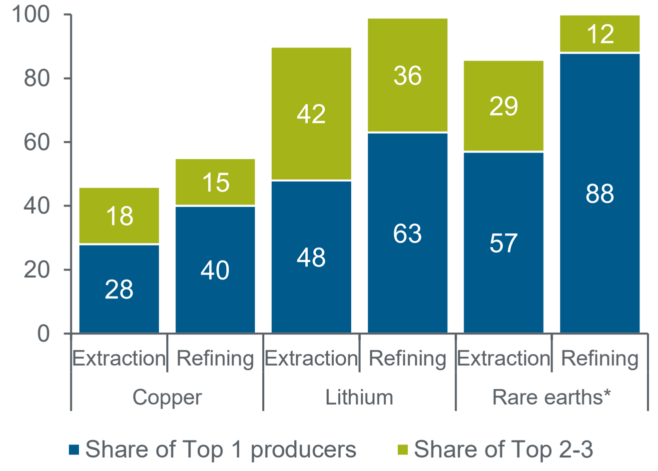
Vulnerabilities in the early stages of the value chain merit particular attention because of Germany's high dependence on raw materials imports

Supply shocks can occur in all stages of the value chain and continue all along the individual processing stages. The geographic concentration of mineral deposits and production in the early stages of the value chain – extraction and refinery – and the associated country risks are decisive in shaping the starting situation. Figure 8 presents the concentration of global production in the largest (top 1) and three largest (top 3) producers of copper, lithium and rare earths in the stages of the value chain for extraction and refining output:

- Copper has the lowest country concentration. At the level of copper refining, however, one country accounts for just under 40% of production: China. In the case of lithium, the high concentration is mainly distributed among the top 3 producers, with Australia accounting for 48% of mine production and China for 63% of refined production. The extraction and refining of rare earths are concentrated even more strongly in the largest producer – China.[37]
- If we include data from the International Energy Agency (IEA), the same applies to lithium and rare earths: Country concentration tends to increase with the processing stage. Market concentration of refining exceeds that of extraction for all three minerals.
- Market concentration on the three largest producers has hardly changed over the past three years. However, the largest copper and lithium mining countries have recently lost production shares.

Figure 8: Geographic concentration of production increases with the processing stage

Shares of the largest (top 1) and three largest (top 3) producers in global production, in per cent



*Rare earths excluding undocumented production in China.
Note: The reference year for copper, lithium and rare earths (extraction) is 2020, for lithium and rare earths (refining) is 2019. Data for rare earths (refining) from the EIA refers to magnetic rare earths: neodymium, praseodymium, dysprosium and terbium.

Sources: Bähr, C. et al. (2024) based on USGS (2023)[38], IEA (2023), KfW Research.

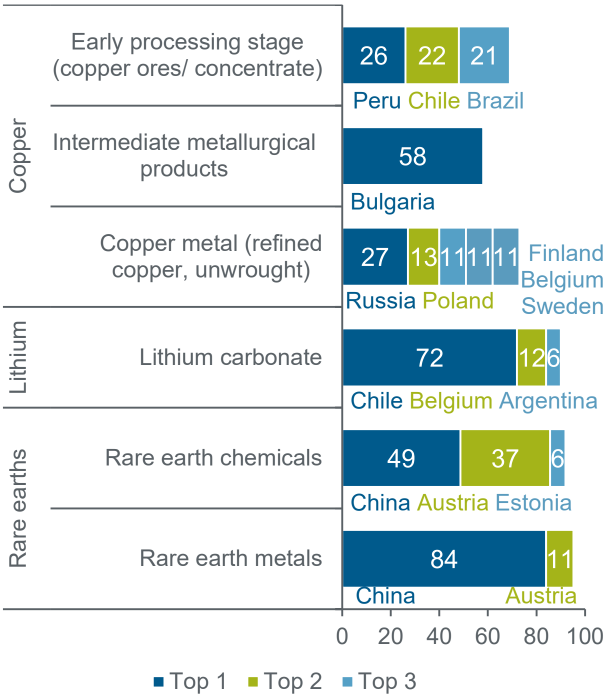
Copper production is sufficiently diversified but some suppliers carry substantial weight for Germany

On average over the years 2016 to 2020, Germany imported around 70% of the copper ore and concentrate obtained at the beginning of the value chain from Peru, Chile and Brazil (see Figure 9). The imports of these minerals demonstrate the high share of these South American countries in mining activity. With 28% of mining output, Chile is the world's largest copper producer. In recent years, however, Chile's dominant position has weakened somewhat, while production in Ecuador and the DR of Congo achieved high growth rates.[39] There is great uncertainty in estimating new production capacities on the basis of planned projects or mine expansions According to the DERA, Peru, the DR of Congo and Russia account for more than half of new production capacity up to 2025.[40]

Supplier country concentration rises substantially already in the first stage of further processing, the conversion of copper ore to copper concentrate. China accounts for around 40%, the largest share of global production. Copper is also refined in Germany (2.5% of global production). For further processed intermediate metallurgical products which, however, only have low import value based on copper content in kilotons, Bulgaria dominates as a source country of German imports (see Figure 10). Bulgaria procures copper ore and concentrate from Georgia, Turkey and Brazil.[41] Finally, Germany also imports large amounts of copper metals such as copper cathodes. Russia supplied 27% of these on average over the years 2016 to 2020. The EU countries Poland, Finland, Belgium and Sweden together supplied just under one half of copper imports in this stage, but this reflects only direct supplier relations (see Box 4).

Figure 9: Germany's imports of tradable products related to copper, lithium and rare earths

Shares of direct supplier countries for imports of selected tradable products of early processing stages, annual average for 2016-2020 in per cent



Sources: KfW Research based on Bähr, C. et al. (2024), UN Comtrade.

Lithium production follows two routes – each with high concentration and, hence, vulnerability to supply shocks

Lithium extraction and processing comprises multiple process routes from which products can be generated that are of equal quality but differ greatly in their processes and geographical routes:

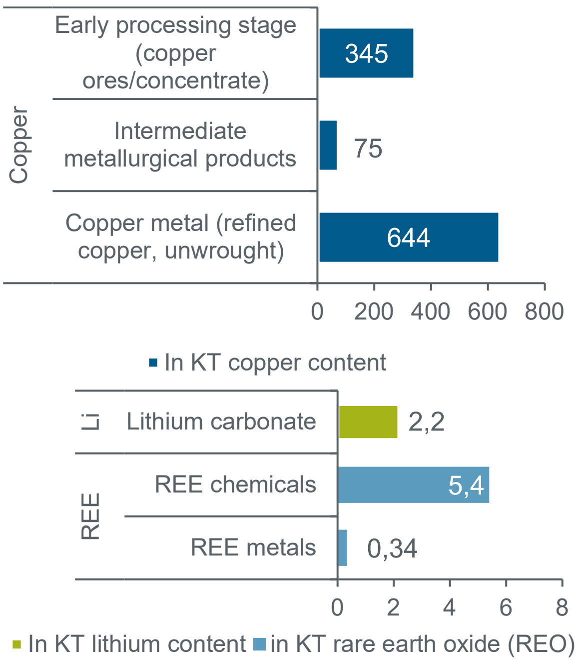
– First, brine is obtained from underground salt lakes through evaporation, from which lithium concentrate is subsequently extracted. In this brine process route, which is mainly used in what is known as the South American lithium triangle (Bolivia, Chile, Argentina), chemicals are used to process the concentrate to lithium hydroxide for export.[42]

– Second, hard rock lithium deposits are mainly extracted in Australia and, to a lesser extent, in Canada, the US and Africa using open-cast mining methods.[43] The lithium ore thus obtained is processed to concentrate and traded internationally. Much of the ore concentrate is exported to Asia, especially China, where it is processed into intermediate products for batteries (lithium carbonate, lithium hydroxide). China also exports these compounds itself and uses both own deposits and imported inputs.[44]

Germany is 100% dependent on lithium imports. With respect to the trading product lithium carbonate, Chile was the most important country of origin for Germany between 2016 and 2020 (see Figure 9). Belgium plays a role as a transshipment point (again, more than 95% comes from Chile, but secondary production is also located here). Direct imports from China take a modest share of 2%. There are no import statistics for the interim product lithium hydroxide/oxide. However, China supplies nearly 70% of global exports, followed by Chile with 11%.[45]

Figure 10: Import value varies by trading product

Germany: Imports, annual average in 2016-2020, in kilotonnes of mineral content



Li=Lithium; REE=Rare Earth Elements

Source: KfW Research based on Bähr, C. et al. (2024).

Rare earths: High dependence on China generates supply chain vulnerability

While rare earths occur in large quantities around the globe, processing the ores and separating the individual oxides is a complex task and takes place only at a handful of production locations, 57% of which are in China, 16% in the US and 13% in Myanmar. In addition, China has a significant if declining share in undocumented production (at least 5% of official production in 2021).[46] In the processing, the concentrate yields chemicals and, in further stages, metals which are internationally tradable intermediate products. These can then be used to manufacture catalytic converters, alloys and magnets as intermediate and final products.

On average in 2016 to 2020, around half of the rare earth chemicals imported by Germany and as much as 84% of rare earth metals came directly from China (see Figure 9). Probably because of a locally domiciled company of the chemical and metallurgical industry, Austria ranks second in the EU for imports of rare earths and therefore occupies an important position as a supplier for Germany. In a number of further processed rare earth products, China's import share exceeds 90%.[47]

Country factors and geoeconomics influence supply-side risks, conditions also play a key role in long-term capacity expansion.

The supply-side risks for individual minerals are associated with high country concentration and are not static but can be influenced by global as well as local developments. At the same time, there is steadily rising global demand for specific minerals for the transition to clean energy technologies and the expansion of digitalisation. On the one hand, this can be expected to create more intense competition for relevant minerals and, potentially, the formation of alliances with like-minded trading partners. On the other hand, the ambition to step up efforts to develop more of the value chain at home is also being increasingly put on the political agendas in the Global South. Accordingly, geopolitical tectonics are of crucial importance for diversifying procurement of raw materials in the future.

Box 4: Albeit a decisive player in raw material supply chains, Asia is underrepresented in Germany's trade statistics.

International trade is of great importance along the copper value chain. Most copper concentrates from South America are smelted in Asia and processed into pre-products in Europe, which roughly represents the middle of the value chain.[48] This is followed by the production of intermediate and final products such as cable harnesses.

The importance of Asian countries, particularly China, for Germany's imports of further processed intermediate products is not evident in the trade statistics under direct supplier countries. It is plausible that EU countries serve as transshipment points for such supplies from Asia.

Asia has a very large market share on the downstream stages of the lithium value chain. Whereas China accounts for only 6% of lithium deposits and 15% of mining output, the country dominates more than 70% of the global market for lithium-ion batteries.[49] The key role of Asia overall and China in particular in the further processing into final products is primarily evident in Germany's imports along the value chain, particularly for finished lithium-ion batteries (68% from China, Korea and Japan).[50] The DERA predicts that most of the further processing of lithium carbonate will remain in the Asian region up to 2030. Besides, China is likely to maintain its share in the further processing of Australian concentrate to lithium hydroxide.

The value chain is different for rare earths, as it is consistently marked by high geographic concentration on China and, in part, Myanmar. Germany also imports a large portion of these minerals directly from China.

The following vulnerabilities may lead to short-term supply scarcity in the international market:

- For copper, the vulnerabilities include political uncertainties, strikes, unrest) and physical risks (extreme weather events, drought in connection with water-intensive extraction) in the main production countries. As was illustrated by the production stop as a result of political unrest in early 2023 at the Chinese-owned Las Bambas Mine in Peru, which accounts for 2% of global production,[51] short-term supply shocks can definitely have an effect on world market prices for copper. From today's perspective, a short-term scarcity could be offset using diversified production chains.
- Short-term shocks in the lithium supply chain could generally be less easily offset than for copper. However, the two main process routes in principle provide options for diversification (brine in Latin America and hard rock in Australia).
- All along the value chain for rare earths, the dependencies and (geo)political risks are primarily linked to the dominant position of China. To a certain extent, this also applies to

the further processing of copper and the refining and further processing of lithium.

Longer-term development of global supply depends on national decisions in the mining countries
In addition, regulatory, political, socio-economic and environmental factors influence the framework for investments that are needed to expand production capacities. Failure to implement investment projects can lead to the long-term relocation of production to other countries or a reduction in output from proven suppliers.

- One factor for shifting production is the effort of many resource-rich countries to localise a larger part of the value chain. The still rather unsuccessful attempts by the Chilean government to increase local copper smelting capacity are one example.[52] Australia, too, is working to develop more of the lithium value chain. [53] Such a shift will not necessarily lead to a shortage in the supply of the mineral but could increase pressure on Germany to import more processed products.
- Chile's prominent position in the early stages of the value chain is under pressure for both copper and lithium. In lithium production, Chile's market share has recently decreased compared with other exporting countries, among other things because complex contract award methods have hampered new projects.[54] Furthermore, the evaporation method is already being affected by growing water scarcity. The water quantity required to produce one tonne of lithium is estimated at approx. 2,000 m^3.[55] It is estimated that South American lithium production will shift more strongly towards Argentina by 2030.[56] Another question is whether lithium production can keep up with global demand, particularly given the expansion of electric mobility in China.[57]
- Developments in the supply of rare earths are mainly determined by China's economic and industrial policy focus. For example, quota regulations on quantities required to remain in the country (for the production of magnets) could gradually reduce export quantities. Global diversification would benefit from the development of alternative extraction sites, which would be possible given that deposits are generally widely distributed. However, the need for environmental compliance makes this a difficult endeavour. The expansion of rare earths processing capacity in the US since 2018 will probably create limited diversification for the European market as it is designed to meet domestic demand. Vertical integration requires a long planning horizon.

Risk mitigating factors exist for copper, technological progress is a key component for lithium and rare earths

There are differences in existing and potential approaches for mitigating risks for copper, lithium and rare earths in the short and longer term. These are summarised in Table 1. Besides geographic diversification of mineral imports, the following questions are of particular concern: Does Germany or the EU produce primary raw materials, or do deposits exist to set up such a production? Are secondary raw materials available? What options for substitution and potentials for efficiency improvements exist? Is stockpiling an option?

Domestic primary raw materials are largely unavailable or not developed, while copper can build on processing facilities.
At present, Germany does not produce any of the three minerals.

- Europe has 6% of the known natural deposits of copper, which are spread relatively widely around the globe. Most of them are in North and South America.
- Germany has 3% of naturally occurring lithium deposits, which are generally extractable but have not yet been economically developed. Around the globe, South America, the US and Australia have large deposits.
- Rare earths comprise a group of individual oxides with extensive deposits spread around the globe (480 million tonnes). However, processing the ores and separating the individual oxides is a complex task and takes place at only a handful of production sites. Germany does not have any meaningful primary deposits.
- Considerable copper processing capacities exist in Germany, and there are also lithium processing capacities which must be developed. There is no relevant processing of rare earths in Germany, and imports mainly involve processed products such as alloys, powders and magnets as a product group.

As secondary raw materials, copper is abundantly available, lithium will be in future, and rare earths are not

When metals are refined not just from mining products but from scrap, this is referred to as secondary refinery. On the one hand, a high share of this is a further source of raw materials, which represents a diversification of available inputs. On the other hand, the availability of secondary raw materials presupposes a preceding value creation process and technical recyclability.

- Around 50% of copper refined in Europe comes from secondary copper gained from scrap copper, which is also exported. Even if the share for Germany is lower, the availability of secondary copper is a considerable risk-mitigating factor from a European perspective as quantities otherwise exported can be redirected to uses within Europe in case of supply disruption. On a global scale, secondary copper makes up around 17% of refinery production, and here as well, China is the largest player.[58]
- There is significant secondary lithium production in Europe. Looking further ahead, however, battery recycling is an additional source with potential for capacity expansion. According to Schmidt (2023), pilot battery recycling plants are gearing up for major quantities of traction batteries to be returned and fed back into the production process.[59] According to McKinsey, recycling lithium-ion batteries could provide around 6% of global lithium production by 2030.[60]
- Pilot or demonstration projects also exist for rare earths recycling in Germany. Their feasibility is mainly based on closed-loop cycles of individual product variants (Japan) or established primary raw material extraction (China). There are technological and economic limitations to a sufficiently broad secondary raw material production.

Table 1: State-of-play and possible approaches for mitigating / avoiding / preventing risks

	Copper	Lithium	Rare earths
Situation			
Germany: dependency on imports	N.A.	100%	100%
Domestic production of primary mineral	No	No, but deposits exist (3%)	No
Domestic processing	Yes, large capacities	Existing capacities under development	No
Diversification of procurement	High	Medium	Low
Diversification of imports of processed goods	Rather high	Low	Low
Risk-mitigating factors			
Availability of secondary raw materials	Yes	R&D on circular economy with long timeframe	Pilot projects only
Options for substitution	Yes, for specific (price-sensitive) products, aluminium, plastics, stainless steel	Difficult owing to purity requirements	Yes, but lower efficiency
Efficiency improvements	Possible in principle	Already efficient, DLE process allows small leaps forward	Little, as efficiency already at maximum
Stockpiling	Yes	No, as technically volatile	No, as processing facilities lacking.
Greater import diversification	Diversification in early stage of VC high already	Possible	Possible to a very limited extent only, requires new extraction sites

Source: KfW Research based on Bähr, C. et al. (2024), Kritisch für die Wertschöpfung – Rohstoffabhängigkeit der deutschen Wirtschaft (*Critical for value added – German industry's raw materials dependency* – our title translation, in German), study for KfW Group, prepared by IW Consult and the Fraunhofer Institute for Systems and Innovation Research.

Options for substitution and more efficient processes often require years of research

– Substitutes exist for copper: depending on use, this can be aluminium, plastic or stainless steel. In price-sensitive products, these are used in response to high copper prices or price volatility.

– The substitution of lithium is the subject of intense research. Given the demands of the mobility sector, lithium is still deemed a non-substitutable mineral. Purity requirements (battery-grade lithium) make substitution a challenge as well. The development of alternative grid storage applications is focusing on sodium-ion technology whose properties, however, make it suitable only for low-capacity uses. But it will likely take at least another decade before new battery concepts are commercially established.[61]

– Existing options for substitution of rare earths in magnets or sensor technology still come at the price of high efficiency losses. Current approaches are aimed more at substitute technologies (such as motors for electric cars and wind generators that do not rely on rare earths).

– The supply of primary raw materials can be expanded by increasing material and resource efficiency. Lithium and rare earth production processes are already deemed very efficient. Further improvements are therefore likely to be only minor. The efficiency of lithium extraction can probably be moderately enhanced as direct lithium extraction ramps up, especially with a view to the limiting environmental factors of conventional brine extraction technology.

There are technical limits to building up stockpiles

A precondition for stockpiling is technological feasibility. While copper is already being stockpiled there are technical limits to the storage of lithium. Storing lithium and rare earths also ties up large amounts of capital, so that any gains from risk mitigation must justify these costs. Furthermore, the actual storage of these minerals is inexpedient when there are no further processing capacities, as is the case for rare earths. If further processed products are indeed stockpiled, it is necessary to take into account the product life cycle and potentially frequent changes in the product specifications required, for example for rare earths.

The different risk profiles make developing a general approach to securing the supply of mineral raw materials a challenge

In order to improve raw material security, it would be advisable to address both the supply and the demand side and to improve the resilience of the economy in general.[62] As the analysis of copper, lithium and rare earths shows, there are differences in the risk profile and risk-mitigating factors for mineral resources. Accordingly, there are different implications to be derived for the private sector and the state in finding the right approach to supply risks and their reduction. This is where mineral raw materials differ from energy raw materials such as oil, which in the end are relatively homogeneous goods, despite all differentiation into heavy and light oils, etc. The requirements for mineral raw materials are very different for the green transformation as well. Thus, compared with other minerals, copper is particularly important for many of these applications. Lithium is used in electric vehicles and storage batteries, and rare earths are also used in wind generators.[63]

With a view to the overall raw material value chain, in Germany it is first and foremost the companies that are called upon to put their supply and value chains on a robust footing and take appropriate measures to ensure their supply of necessary resources and resource-containing inputs. With regard to government support, the heavily differentiated requirements for individual raw materials make it appear expedient to select measures that apply to all materials and not to specific ones. Also conceivable is a modular system that can be accessed by each of the raw materials in accordance with their specific risk profile. In this way, the relevant risk-mitigating factors can be more accurately taken into account while reducing limiting factors. Lithium, for example, cannot be stockpiled because it is unsuitable for storage, but strengthening R&D is likely to benefit the development of possible substitutions, for example for batteries. It is true that rare earths are characterised by high market concentration and China's dominance of the market in the early stages of the value chain. At the same time, there are insufficient domestic processing capacities that would benefit from greater import diversification. The latter is more relevant for further processed goods containing vulnerable imports of rare earths. Irrespective of this, it remains important to pay close attention to the supply security of raw materials for technologies deemed particularly critical. However, the information requirements regarding the future development of supply and demand, including further technological developments, are very high, so that a degree of openness to raw materials and technologies is desirable.

Strengthening risk-mitigating factors

A number of proposals have been made for improving raw material security in the EU and Germany, so several selected aspects are reviewed here. The analysis thus far undertaken generally highlights the need to strengthen risk-mitigating factors by reducing the consumption of primary raw materials as an initial starting point. This could be achieved by using more secondary raw materials, substituting critical raw materials and more efficient production. With a view to the three minerals reviewed here, the following considerations can be made:

– For copper, secondary raw materials and recycling are already widely available, covering a substantial portion of the supply. For lithium and rare earths, however, secondary raw materials do not play a significant role yet in Europe. Relevant potential exists for lithium from batteries, so that their industrial-scale recycling is currently being tested and developed. For rare earths, however, relevant projects are still in the pilot and demonstration stage.

– Substituting these minerals requires both technological capabilities and appropriately cost-effective and efficient substitutes. In specific applications, copper can be substituted with aluminium, titanium, steel, fibreglass or plastic.[64] In electrical applications, substitution with silver is not cost-effective, but aluminium is already being used in the transmission and distribution of electricity.[65] Lithium can potentially be substituted with calcium, magnesium, mercury or zinc. Because of the requirements of the mobility sector, lithium is currently regarded as non-substitutable in batteries.[66] However, sodium-ion batteries can be used in specific applications. The existing options for the substitution of rare earths come with efficiency losses with respect to both the minerals themselves and the technologies.[67]

– A high degree of efficiency has already been determined for lithium and rare earths. But as research and development in technologies of the future is continuing, it cannot be ruled out that alternative applications and further technological developments will emerge.

Options for reducing the use of primary raw materials would benefit from both basic research and applied R&D and, hence, corresponding research funding by the state. Material and resource efficiency is already being supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (e.g. ProgRessIII: BMUV, 2020). The development and expansion of recycling systems, on the other hand, is resource-specific, and the state can be seen as a provider of support in the areas of coordination between businesses, development of collection infrastructure and the setting of standards for take-back or return obligations.

Expanding procurement sources

The reduction of import risks can generally be achieved by diversifying suppliers and supported by building up stockpiles. For copper, lithium and rare earths, high supplier concentration was identified as a major source of risk. At the same time, with the exception of rare earths, Germany procures the critical raw materials that are used in at least five key technologies and have a high market concentration from at least four of the five largest global exporters, which amounts to a relatively high diversification under the current circumstances.[68] Nonetheless, each company needs to verify whether its suppliers are sufficiently diversified. This also includes cost aspects – coordination efforts, higher prices for smaller purchase quantities – that need to be weighed against expected loss of revenue from a supply shock.

Promoting and developing the further processing of primary raw materials in Germany or Europe would be another way to expand diversification. This would also eliminate the country risk that explains some of the supply risks. Relevant approaches include, for example, the project to extract lithium from deep aquifers in the Upper Rhine Valley[69], plans for extracting lithium from the Ore Mountains in eastern Germany[70], the exploration of copper deposits in Lusatia[71] or the discovery of rare earths deposits in Sweden.[72] However, the long time horizon, capital intensity and competitiveness of production, environmental impacts and local acceptance must be taken into account. Creating favourable conditions in this area would be an explicit task of the state. With regards to stockpiling as an approach to expand available supplies, technological feasibility and the broader life cycle of the respective raw material need to be taken into account.

Creating favourable conditions – a sovereign task

As is the case in other fields of business management, the state in particular is called upon to create favourable framework conditions here as well. This applies first and foremost to the conditions at home. But in securing raw materials supplies it also applies to international relations with the source countries of primary raw materials and further processed products. In the cooperation between states, the primacy of the EU applies when it comes to foreign trade policy measures. Germany has already entered into raw materials agreements with Kazakhstan, Mongolia and Peru and concluded raw materials partnerships with Australia, Chile, Ghana and Canada. The heightened awareness of geoeconomic risks to the supply of raw materials is expressed in the German Federal Government’s China strategy, which also makes reference to raw materials partnerships and explicitly focuses on further processing capacities in the producing country.

Company-specific measures and state support both rely on having sufficient information about the global raw materials situation, imports and the companies’ supply and value chains. Given the production links, the need for information goes beyond the immediate suppliers as shocks can spread through the value chains. Likewise, economic linkages with other countries are relevant across the entire value chain, as the analysis of at-risk imports has shown. It is also necessary to assess the risks. Assessing countries is particularly challenging in the current environment of geopolitical and geoeconomic upheavals. For small and medium-sized enterprises, the fixed costs of obtaining and assessing information play a particularly large role, especially if they go beyond their direct suppliers. Strengthening awareness of country risks along the value chain and expanding information offerings can definitely prove to be useful and help to align the risk assessments by enterprises and society.

Outlook

Concerns about the supply of raw materials and their long-term security are an old familiar phenomenon in Germany. But the dual transformation, the rapid progression of which poses a particular challenge for the supply of mineral raw materials, is giving heightened urgency to raw materials security. This is compounded by the geoeconomic changes and the stronger emphasis given to the aspect of security in foreign trade relations, leading to a reassessment of country risks for the supply of raw materials.

The minerals copper, lithium and rare earths examined here and their processing all along the value chain are relevant for value creation and employment in Germany's manufacturing sector – if to varying degrees. This is particularly evident in a sector analysis, which has shown that the largest segment of the manufacturing sector by gross value added, the production of motor vehicles and vehicle parts, is particularly dependent on these three minerals.

The risks to the supply of raw materials and products containing raw materials result primarily from the concentration of suppliers. Approaches to diversifying trading partners will therefore be at the heart of strategic measures aimed at enhancing the resilience of raw material supply chains in the future as well. At the same time, the risk profiles and risk-mitigating factors for securing the supply are different for each raw material. Accordingly, the focus should rather be placed on a balanced catalogue of measures than on any particular instrument. This would have to be designed in such a way that it helps businesses in various stages of the value chain to responsibly manage supply risks for various raw materials and helps to reduce these risks. One example of an overarching instrument is to promote technological progress that may provide outcomes in the area of substitution or material efficiency. Finally, a favourable and steady enabling environment would set the course for private investment in resilient and future-oriented raw material supply chains.

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