The Green Gamble: The Geopolitics of Net Zero

Prof. Doug Stokes

Executive Summary

Access to Energy and Economic Abundance

Energy accessibility and economic abundance are closely linked. Global primary energy use and global Gross Domestic Product ("GDP") have grown at approximately the same yearly rate since 1900. Conversely, the opposite also holds—higher energy prices may contribute to reduced economic outputs, leading to recessions and job losses. Without access to affordable energy, it would become increasingly difficult to alleviate poverty, produce food, and create opportunities for meaningful work. As industrialised nations transition to cleaner technologies, they must not lose sight of this fundamental relationship running through the energy supply chain.

Across the industrialised world, a historically unparalleled shift is occurring as countries transition from fossil fuels to clean "net zero" carbon energy, where greenhouse gas emissions produced by human activity do not exceed the emissions removed from the atmosphere each year. The scale of this change is immense. The United States, the United Kingdom, and the European Union have committed to achieving a clean energy economy with net zero emissions by 2050.

New, green technologies are at the heart of the industrial transformations driving the net zero agenda, which relies on a complex global supply chain composed of various resources, minerals, and materials used to produce, store, and use renewable energy. But where do these resources come from? How reliant are developed countries on energy exports to fuel the net zero transition? What happens if the global supply chains are disrupted?

China Powers Net Zero

Mapping where renewable energy resources come from reveals that China is the dominant producer of many materials used in solar panels, electric vehicles, and wind turbines. In countries like the Democratic Republic of Congo ("DRC"), China retains control of production because it owns most of the mines in the DRC. Developed countries depend on exports from these countries to power the green transition. Take rare earth elements ("REEs") for example. Currently, the United States does not have any facilities capable of processing REEs; China produces most of the global supply, yet it restricts exports through quotas, licenses, and taxes.

As the West moves towards net zero, its demand for critical minerals is increasing at a pace that far outstrips current domestic supply capabilities. This imbalance makes the system vulnerable to geopolitical risks, export restrictions, and potential price volatility. Western countries are inadvertently driving their energy systems into ever-increasing dependency on China in the pursuit of net zero targets. But policymakers must consider how to achieve energy security through the appropriate balance between state intervention and market forces and find solutions to China's rare-earths dominance through new alliances and supply chain diversification. The West cannot turn the lights off on its legacy infrastructure until it is confident it can keep the lights of renewable energy switched on.

Mapping Global Supply of Renewable Resources:

Material	Total Production Worldwide (thousand metric tons)	Top Countries by Approx. % of Global Production, 2022	Primary Uses in "Green Transition"
Aluminium	69,000	China 58% India 6% Russia 5%	Solar panels Electric vehicles Wind turbines
Arsenic	61,000	Peru 46% China 39% Morocco 11%	Solar Panels
Cobalt	190,000	Democratic Republic of Congo[1] 68% Russia 5% Australia 3%	Electric vehicle batteries Renewable energy storage
Copper	22,000 26,000	**Mine Production** Chile 24% Peru 10% Democratic Republic of Congo 10% **Refinery Production** China 42% Chile 8% Democratic Republic of Congo 7%	Geothermal energy technology Energy storage
Gallium	550,000	China 98% Russia <1%	Electric vehicles Solar panels
Germanium[2]	140,000	China 68% Russia 4%	Electric vehicles Solar panels
Graphite	1,300,000	China[3] 65% Mozambique 13% Madagascar 9%	Electric vehicle batteries
Indium	900	China 59% Republic of Korea 22% Japan 7%	Solar Panels
Lithium	130,000	Australia 47% Chile 30% China 15%	Electric vehicle batteries
Manganese	20,000	South Africa 36% Gabon 23% United States 17%	Electric vehicle batteries Renewable energy storage
Nickel	3,300,000	Indonesia 49% Philippines 10% Russia 7%	Electric vehicle batteries Renewable energy storage
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Silicon	8,800	China 68% Russia 7% Brazil 5%	Solar panels

Silver	26,000	Mexico China Peru	24% 14% 12%	Solar Panels
Steel (raw)	1,900	China India Japan	52% 7% 5%	Geothermal energy technology
Tellurium	640	China Russia	53% 13%	Solar Panels

Source – United States Geological Survey, mineral commodity summaries 2023.

[1]China leads the world in refined cobalt production at 70% of total global supply, owning 15 of 17 industrial cobalt operations in the DRC.

[2]These figures are taken from the 2022 Survey, as the 2023 could not access data surrounding Germanium production.

[3]China also dominates in refining battery-grade raw graphite, controlling 80% of global production.

[4]Myanmar and China share the world's supply of Heavy REEs. Still, only China has the industrial capacity to process these elements, reinforcing its dominance over the REE market, with Myanmar becoming China's largest source of heavy rare earth elements.

The Green Gamble:

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Responsible Stewardship and "Net Zero" Commitments

Responsible stewardship views caring for the environment and preserving it for future generations as compatible with providing access to clean and affordable energy. Energy heats homes and powers nations. A stable, sustainable energy supply is vital for individual prosperity, economic growth, and productivity. There is a close connection between energy availability and economic prosperity—global primary energy use and global Gross Domestic Product ("GDP") have grown at approximately the same yearly rate since 1900. Conversely, the opposite also holds—higher energy prices may contribute to reduced economic outputs, leading to recessions and job losses. Without access to affordable energy, it would become increasingly difficult to alleviate poverty, produce food, and create opportunities for meaningful work.

As industrialised nations transition to cleaner technologies, they must not lose sight of this fundamental relationship across the energy supply chain. Across the industrialised world, a historically unparalleled shift is occurring as countries transition from fossil fuels to clean "net zero" carbon energy, where greenhouse gas emissions produced by human activity do not exceed the emissions removed from the atmosphere each year. The scale of this change is immense. The United States, the United Kingdom, and the European Union have committed to achieving a clean energy economy with net zero emissions by 2050. To reach this ambitious target, each government has agreed to at least halve greenhouse gas emissions by 2030 and has announced considerable investments in clean energy technologies and infrastructure to achieve this transition—the United States has committed $2 trillion,[1] the United Kingdom £12 billion,[2] and the European Union €1 trillion.[3]

New, green technologies are at the heart of the industrial transformations driving the net zero agenda, which relies on a complex global supply chain composed of various resources, minerals, and materials used to produce, store, and use renewable energy.[4] For example, lithium-ion batteries store excess solar and wind energy so businesses and homes can continue to use renewables without sunshine (solar panels) or wind (wind turbines) or to manage peaks and troughs in energy supply and demand without relying on fossil fuels. Lithium, cobalt, nickel, and rare-earth elements are vital components of these batteries, and demand for these minerals will significantly increase in relation to the net zero goals each country sets. The global demand for batteries is predicted to rise from 185 gigawatt-hours in 2020 to over 2,000 by 2030.[5] Several other renewable energy supply chain components—from solar panels to electric vehicles ("EVs")—also rely on these and other minerals. Yet, China dominates the market for these minerals with considerable control over the raw resources, production, and trade.

These net-zero technologies create ever more complex global supply chains. The demand for nickel, cobalt, and rare-earth elements will see anticipated growth rates of 140 times, 70 times, and a significant increase for rare-earth elements, respectively. The International Economic Agency's ("IEA") 2022 report concludes that "most of the output growth for lithium, nickel and cobalt are expected to come from today's major producers, implying a higher concentration in the years ahead. Under these circumstances, physical disruptions or regulatory and geopolitical events in major producing countries can greatly impact the availability of minerals, and in turn on prices."[6]

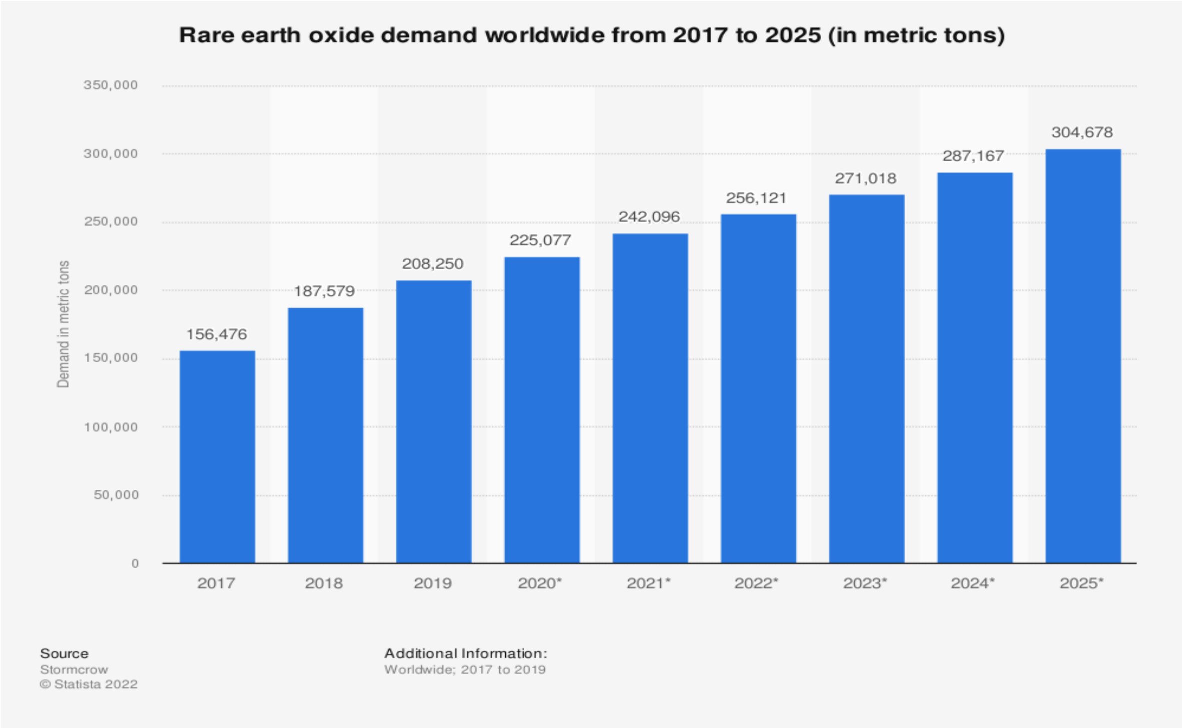

Figure 1[7]

While environmental sustainability is a primary concern among industrialised nations, energy sustainability has not received similar attention. Industrialised nations have made a "green gamble". Their net-zero targets heavily rely on imports of resources and minerals from China, which controls the largest global share of reserves and production, and they assume access to this market will continue without interruption. Findings from the 2023 US Geological Survey illustrate this dependency: China controls over 50% of the production of minerals critical for net-zero targets. Yet, the United States depends solely on imports for 12 minerals and imports 50% of an additional 31 critical minerals used for renewable energy.[8] This gamble may pay off, but it also makes Western countries vulnerable to external factors that could limit or stop access to reliable renewable energy supplies.

Demand for these resources will increase across developed economies as countries pursue their net-zero targets. From 2023-2040, demand for neodymium ("NdFeB") magnets, for example, is projected to grow at a compound annual growth rate of 7.5%, fuelled by the energy transition. The global permanent magnet market is also poised to grow from $34.4 billion in 2021 to $54.1 billion by 2026. By 2040, there could be an annual global undersupply of NdFeB alloy and powder of 246,000 tonnes. If we take the EU alone, its rare earths demand will increase with electric vehicle production, as 95% of electric vehicles use rare earth-containing traction motors. Usage from this sector could rise from 5,000 tonnes in 2019 to 70,000 tonnes by 2030, *an increase of 1,300%*.[9]

China is positioned to capitalise on this increased demand. In 2021, China consolidated its monopoly of rare earths by merging three state-owned firms, forming China Rare Earths, which now accounts for 70% of the country's rare earth production.[10] China's vast dominance in the crucial heavy rare earths sector is vital for magnetics and military equipment. China and Myanmar are the leading producers of these elements, with Myanmar supplying nearly half of China's heavy rare earths. By 2022, China controlled 85% of global rare earth processing, 70% of production, and 92% of rare earth magnet production. China also holds more rare earth patents than the rest of the world combined.[11]

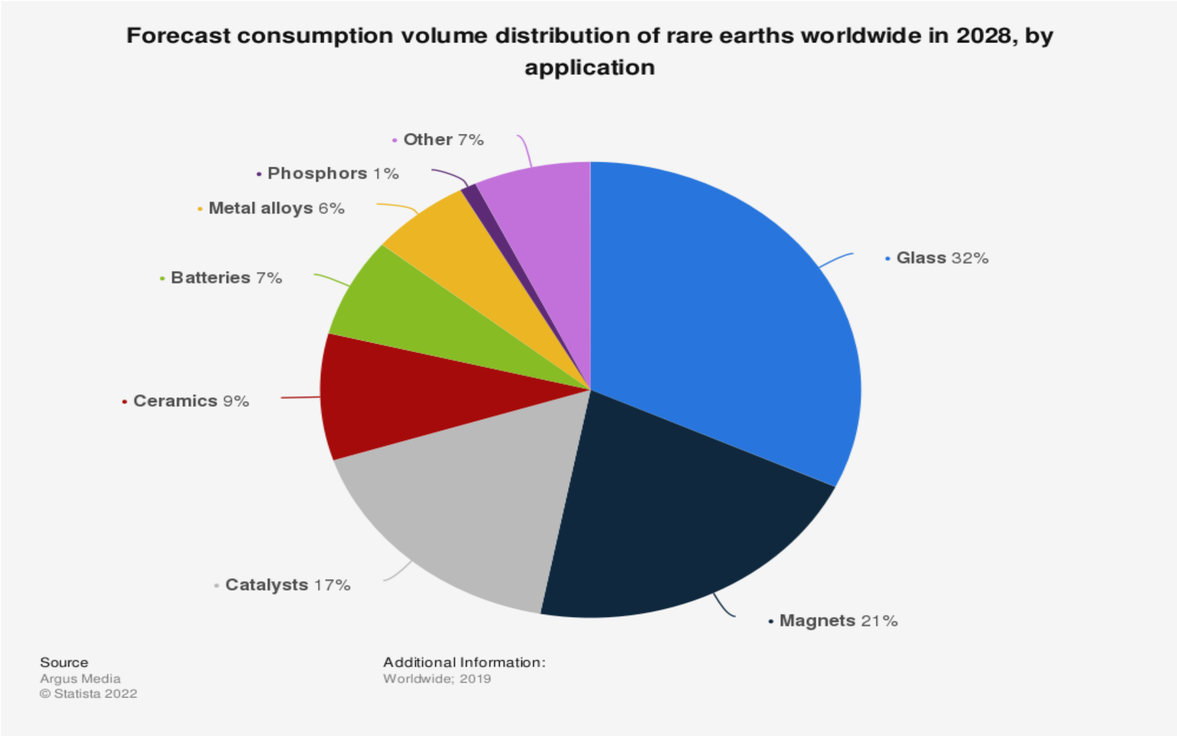

Figure 2[12]

As the West moves towards net zero, its demand for critical minerals is increasing at a pace that far outstrips current domestic supply capabilities. This imbalance makes the system vulnerable to geopolitical risks, export restrictions, and potential price volatility. In a disturbing echo of the past, our drive for net zero emissions and clean energy technologies may inadvertently usher in a new era of resource dependency, not unlike the oil crises of the 20th century. Still, with a new set of resource-rich, heavily industrialised, and, in some cases, peer competitor countries controlling the supply of commodities upon which the very nature of our industrial civilisation depends, the West's energy transition inevitably means it will become increasingly reliant on critical resources, production process, and global supply chains outside of its control.

This paper explains that Western countries are inadvertently driving their energy systems into ever-increasing dependency on China to pursue net zero targets. It begins by explaining the technologies used to generate renewable energy and the minerals and resources required to operate those technologies. It then identifies the source countries where these minerals and resources are found, produced, and ultimately traded to Western countries. The next sections of the paper examine geopolitical risks, supply chain vulnerabilities, and risk mitigation strategies. It then considers an appropriate balance between state intervention and market forces in the quest to find solutions to rare earth dominance through new alliances and supply chain diversification. The paper then concludes with an analysis of the implications of this data, including whether the status quo is sustainable and whether additional strategies should be deployed.

Sustainable Synergies? Understanding New Technology and Mapping Supply Chains and the Refinery Process

As the world transitions towards a net zero future, it is essential to understand the key sectors, resources, and industrial processes involved. This chapter identifies those critical elements, the nodal points in developed and nascent global supply chains, and the key players and multinational corporations helping shape future industries.

Mapping these interdependencies across different sectors, this chapter highlights the significant role of countries such as China, Australia, Russia, the United States, and European nations in the supply chains for solar panels, wind turbines, and electric vehicle technologies. This chapter begins with an explanation of the different technologies involved in the "green transition", followed by a detailed analysis of the most prominent minerals and resources used in renewable technology, the regions where they are found, and future trends in demand.

Renewable Energy Technologies

Renewable energy technologies are indispensable for the net zero transition. These technologies include solar panels, wind turbines, and geothermal energy. Lithium batteries, which power electric vehicles and are used for energy storage, are integral to these technologies. According to the US Geological Survey, the critical mineral commodities used in solar panels are arsenic, gallium, germanium, indium, and tellurium. For wind turbines, these commodities include aluminium and rare-earth elements, which are crucial for permanent magnets for wind turbines and electric vehicle motors. Batteries rely on cobalt, graphite, lithium, and manganese for performance, longevity, and energy density.[13] These technologies also depend on silver, silicon, copper, nickel, and steel. All of these minerals are sourced and processed by different countries worldwide. The global supply chain for these materials is complex and interdependent, reflecting the international cooperation necessary for the large-scale development of renewable energy technologies.[14]

Where Does Renewable Energy Come From?

Mapping the production of these resources by country reveals China's balance of power in the global supply chains that underpin the green transition.

What are some of these key resources?

Material	Total Production Worldwide (thousand metric tons)	Top Countries by Approx. % of Global Production, 2022	Primary Uses in "Green Transition"
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Silicon

Silicon is essential for the net zero transition due to its critical role in solar panel production and its applications in various industries, contributing to energy efficiency and emissions reduction. Major companies in this sector include Norway's Elkem, the United States' Hemlock Semiconductor, and Germany's Wacker Chemie.

China has emerged as a dominant player in the silicon market, accounting for approximately 65% of global production in 2021 (rising to 68% in 2022); 25% of its production is exported mainly to Japan, Thailand, and India.[15] Other leading producer countries include the Russia (7%), and Brazil (5%).[16] In 2020, the global silicon metal production capacity reached 6.5 million metric tons ("mt"), with China contributing significantly to this figure by producing 5.17 million mt. Between 2013 and 2020, China's contribution to the global increase in industrial silicon capacity was substantial, accounting for 1.72 million mt out of the total growth of 1.85 million mt, a staggering 93% increase in global industrial silicon capacity. While capacity utilisation rates in countries outside China fell to 60% in 2020, China maintained a stable rate of around 50%, which increased to 60% in 2021.[17] The stability in China's silicon production capacity utilization rates can be attributed to its substantial investment in clean energy and its "Made in China 2025" strategy that bolstered domestic semiconductor production, further driving silicon demand.

Silver

Silver is also crucial for the renewable energy sector due to its high conductivity and low resistance, which make it an ideal material for electrical contacts in solar panels. The demand for silver in the renewable energy sector is driven by expanding solar energy installations and increasing investments in clean energy technologies. Global silver production was primarily sourced from Mexico (24%), Peru (18%), and China (15%) in 2021.[18] These figures changed marginally to Mexico (24%), China (14%), and Peru (12%).[19] Some of the leading silver mining companies include Mexico's Fresnillo, Poland's KGHM, and Switzerland's Glencore.[20]

Aluminium

Aluminium is another vital component in renewable energy technologies, particularly in solar panel frames and wind turbine structures, due to its lightweight, high strength, and corrosion resistance. It is also an essential component of electric vehicles. China is dominant, producing around 55% of the global supply in 2021, rising to 58% in 2022.[21] Other significant aluminium producers include Russia (6%), Canada (5%), and India (5%) in 2021. These shares changed marginally to India (6%), Russia (5%), and with Canada's contribution dropping to 4%.[22] Key companies in this industry are China's Chalco and Hongqiao Group, Russia's Rusal, the Anglo-Australian Rio Tinto, and the United States' Alcoa (with the production costs at Rusal rising by 33% in 2022 due to the Ukraine conflict). The aluminium sector's growth is expected to be driven by increasing demand for renewable energy infrastructure, especially the rising use of electric vehicles.[23]

The benefits aluminium brings to greenhouse gas reduction must be balanced against the environmental costs of aluminium production. Mining, refining, and smelting processes have traditionally been energy-intensive and pollute the environment. Thus, as the demand for aluminium in clean technologies increases, there is an increasing imperative to make aluminium production more sustainable. This objective will involve exploring more energy-efficient production methods, potentially incorporating renewable energy sources, and better waste management practices.

Rare-Earth Elements

Wind power technology relies heavily on rare earth metals like neodymium and dysprosium to manufacture high-performance magnets in wind turbines and motors in electric vehicles. As we will see throughout this report, magnets play a central role in the new green technologies due to their ability to convert energy efficiently and effectively. High-performance rare earth magnets, such as those made from neodymium and dysprosium, are essential in manufacturing wind turbines that convert the wind's kinetic energy into electricity. Rare earth magnets provide exceptional performance, allowing compact and powerful generators to produce more significant amounts of electricity from the same amount of wind energy.[24] Again, China is the world's largest producer of these rare earth metals, accounting for 70% of global annual mine production in 2022. Other significant producers include the United States (14.3%), Australia (6%), Burma (Myanmar) (4%), and Thailand (2.4%).[25]

China's control of approximately 60% of mining operations, over 85% of processing capacity, and over 90% of magnet production underpins its supremacy in the rare-earths sector. Even though the United States produces a sizeable portion of the global rare earths supply at its Mountain Pass mine in California, it typically sells the concentrate extracted from that mine to Chinese refiners.[26]

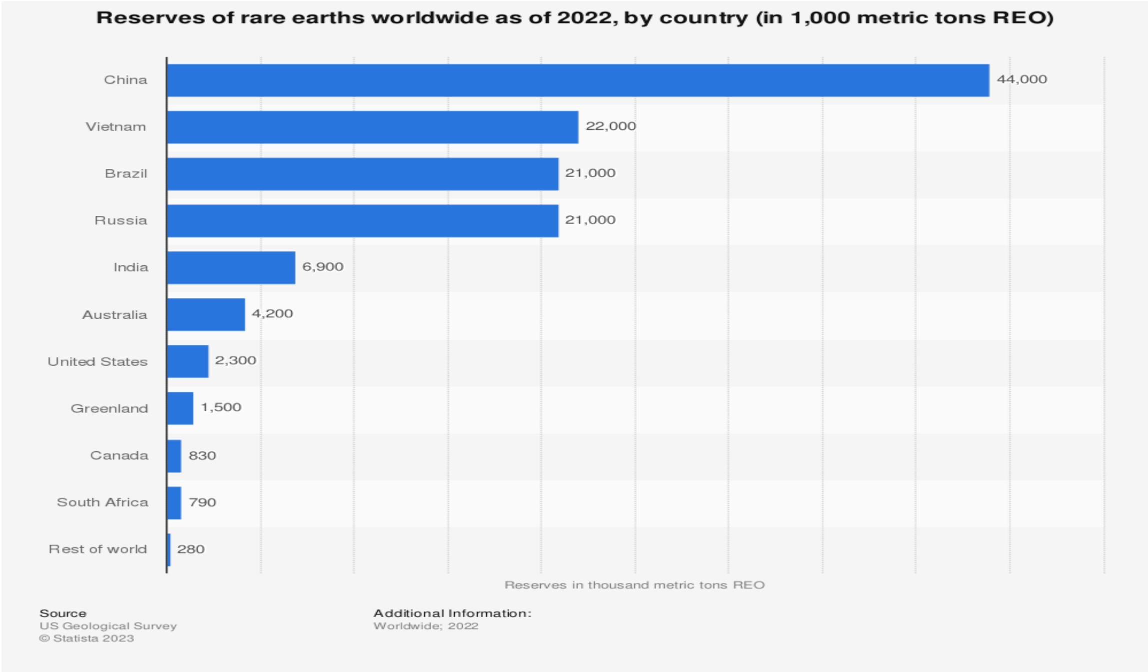

Figure 3[27]

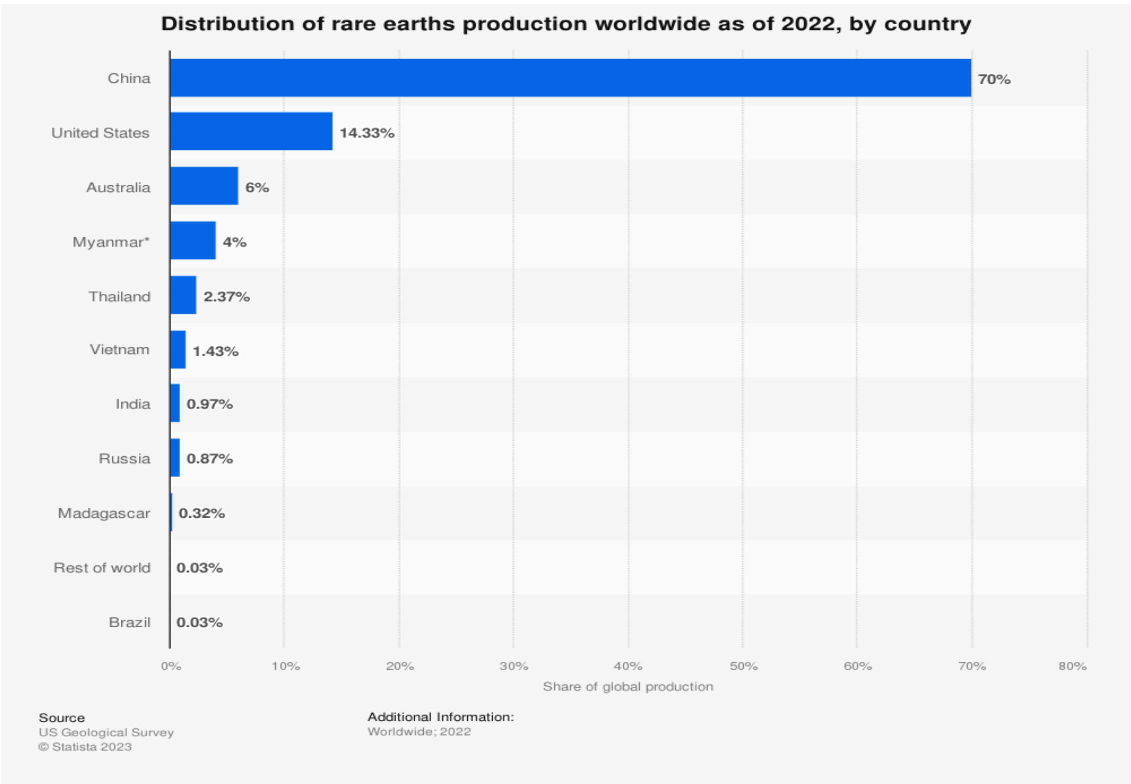

Figure 4[28]

Steel

Geothermal energy, another crucial renewable technology, depends on materials such as steel, copper, and various alloys for construction and operation. Steel production is dominated by China, which accounted for nearly 53% of global output, followed by India (5.9%), Japan (5.3%), and the United States (4.6%) in 2021. These figures changed marginally to China (54%), India (6.6%), the United States (5.9%), and Japan (4.7%) in 2022.[29] Copper was primarily sourced from Chile (28%), Peru (12%), and China (9%) in 2021. Both steel and copper are essential for geothermal energy systems due to their high thermal conductivity and mechanical strength.[30]

Copper

Along with steel, copper is essential for geothermal energy systems due to their high thermal conductivity and mechanical strength. Copper production, which includes mining, refining, and processing, is a global undertaking, and different countries specialise in distinct stages of the process. In 2022, worldwide copper mining production stood at an estimated 22 million metric tons, with Chile the leading producer of copper with 5.6 million tonnes, accounting for 27% of global production. It was followed by Peru with 2.2 million tonnes (10%), China and the Democratic Republic of Congo each with 1.8 million tonnes (8%), the United States with 1.2 million tonnes (6%), Australia with 0.9 million tonnes (4%), and Russia with 0.8 million tonnes (4%).[31]

The refining stage transforms the mined rock, typically containing less than 1% copper, through grinding, concentrating, and refining, often in refining plants distant from the mines. Major copper refineries are traditionally found in Chile, Japan, the United States, and China.

After refining, copper is processed into various industrial and consumer goods, including electro-refining for high-purity copper or smelting and alloying for specific product types. These activities occur in the same nations that undertake mining and refining, such as Chile, Peru, China, and the United States. China leads on the refinery of copper, accounting for approximately 42% of global refinery production.[32]

That said, not all nations engaged in copper production participate in all life cycle steps, from mining to processing. Countries often specialise according to their resources and infrastructure, creating a varied list of countries engaged in each stage. Furthermore, the export of ore for smelting leads to discrepancies between a nation's smelter production and mined production of copper.

Lithium

Lithium plays a vital role in manufacturing electric vehicle batteries, and demand for lithium has surged with the growth of the electric vehicle market. In 2023, lithium production is concentrated in a select few countries.

Accounting for 47% of global production, Australia is the top lithium producer worldwide, reflecting the nation's vast mineral resources and technical capabilities in mining. Chile trails closely as the second-largest lithium producer globally at 30%, whilst China is ranked third at 15% (in 2022). Despite facing challenges related to higher production costs and environmental concerns, China has committed to the growth of its lithium industry. In a testament to this, the country has even extended its reach to Bolivia, initiating lithium extraction after signing a significant $1 billion agreement with the Bolivian state company, Yacimientos de Litio Bolivianos. Major lithium mining companies include Australia's Talison Lithium, Chile's Sociedad Química y Minera, and the United States Albemarle Corporation.[33]

Afghanistan, a country battling political instability, holds vast lithium reserves and other metals for electric vehicles. Intriguingly, there are indications of potential collaboration between the Taliban and Chinese partners to utilise these valuable resources. Lastly, the United States is making notable strides in the lithium production industry, intending to increase its production in 2023, with Lithium Americas Corp set to commence operations.

Nickel, Manganese, and Graphite

Nickel, cobalt, manganese, and graphite are crucial to battery performance, longevity, and energy density. These minerals are prevalent in manufacturing batteries for electric vehicles and renewable energy storage systems. Indonesia has led consistently in global production of nickel at approximately 49% in 2022.[34]

South Africa is the largest manganese producer, accounting for approximately 36% of global production in 2022, and it plays a pivotal role in battery performance and clean energy technology production.[35]

China stands out in the graphite industry, not only as a top raw material producer but also as a dominant force in refining battery-grade raw materials, controlling about 80% of global production. Its dominance will be strengthened by the anticipated growing demand in the EV battery industry. China also produces 65% of the world's graphite.[36]

Cobalt

Cobalt is also an essential element in EV batteries. In 2022, the Democratic Republic of the Congo ("DRC") was the world's largest producer of cobalt, accounting for about 68% of the global mined cobalt supplies. The DRC's significant share of global cobalt production can be attributed to its vast reserves, home to half of the world's known cobalt resources.[37] However, the cobalt mining industry in the DRC has been plagued by human rights abuses, poor governance, and security concerns. The artisanal and small-scale mining ("ASM") sector, which contributes to a considerable portion of the country's cobalt production, has been associated with child labour, hazardous working conditions, and the exploitation of miners. Security concerns, including armed groups, have also plagued the DRC. Kidnappings and killings have also often been linked to conflicts over control of mineral resources or disputes between rival armed groups.

Chinese companies have made significant investments in the DRC's cobalt industry, securing access to cobalt resources and influencing the supply chain. One of the largest is China Molybdenum, and in 2016, it acquired the Tenke Fungurume copper-cobalt mine in the DRC. The mine is one of the largest and highest-grade copper and cobalt deposits globally, with China Molybdenum holding an 80% stake in the project.[38] As a result, China has considerable influence over the cobalt supply chain in the DRC and, more broadly, makes it a key player in the global cobalt market.

Glencore PLC, based in Baar, Switzerland, leads the global cobalt mining industry with an annual revenue of $203.8 billion. It is followed by Vale S.A. from Rio de Janeiro, Brazil, with $54.5 billion, and Gécamines from Lubumbashi, Democratic Republic of Congo (DRC), with $33.69 billion. Next is Eurasian Resources Group from Luxembourg at $33 billion, and China Molybdenum Co. Ltd from China with $24.1 billion. Zhejiang Huayou Cobalt Co. Ltd, also from China, has $4.792 billion, while Umicore from Brussels, Belgium, stands at $4 billion. Rounding out the top ten are Jervois Global Limited from Australia, with $162 million; Sherritt International from Toronto, Canada, with $110 million; and Panoramic Resources Limited from Australia, at $90.39 million. These rankings, based on annual revenue, highlight the competitive landscape of the cobalt mining sector. Moreover, the International Energy Agency ("IEA") forecasts that demand for cobalt will quintuple between 2020 and 2040.[39]

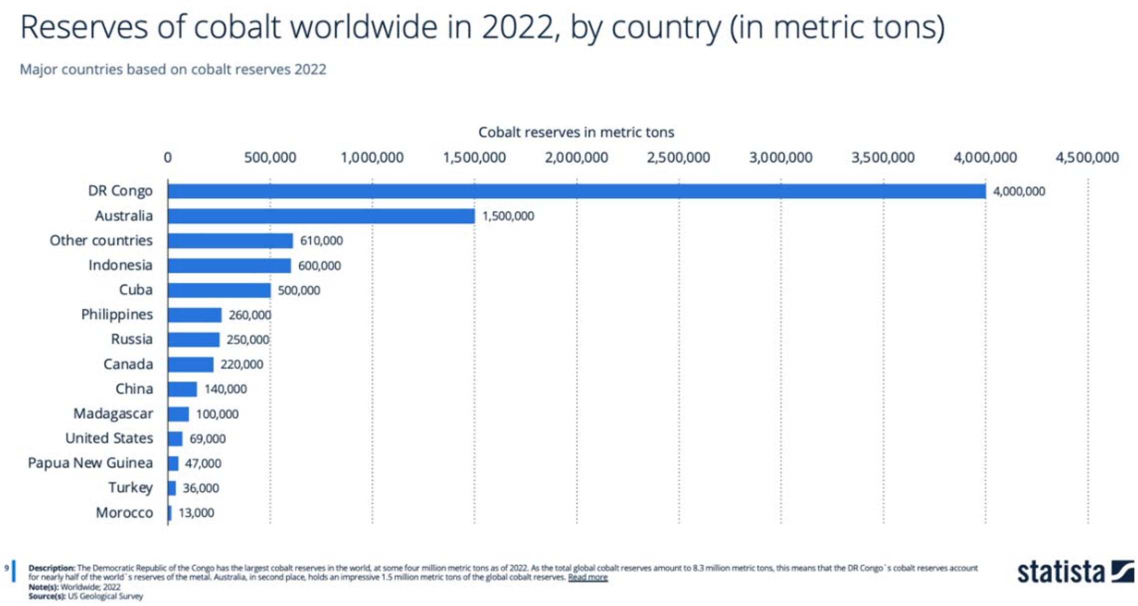

Figure 5[40]

Energy Storage

Adopting and developing energy storage technologies are essential for achieving net zero emissions and supporting a low-carbon energy transition. Energy storage technologies, including batteries, hydrogen storage, and other methods, are crucial in balancing the intermittent nature of renewable energy sources like solar and wind power. These technologies rely on various resources, each with unique production and processing chains that involve several countries and key industry players.[41]

Batteries, particularly lithium-ion batteries, are widely used for energy storage due to their high energy density and decreasing costs. As mentioned earlier, lithium is predominantly sourced from Australia, which accounts for around 47% of global production, Chile at 30%, and China at 15%.[42] Cobalt, another essential element in lithium-ion batteries, is primarily produced in the Democratic Republic of the Congo, contributing to approximately 70% of global production. Russia and Australia are other significant producers. Major lithium-ion battery manufacturers include China's Contemporary Amperex Technology ("CATL"), South Korea's LG Chem, and Japan's Panasonic.

Hydrogen storage is another promising technology that can store and release energy through fuel cells or combustion. Hydrogen can be produced using renewable electricity from various sources, including natural gas, biomass, and water electrolysis. Currently, most hydrogen production comes from natural gas reforming, with the United States, Russia, and Canada being the largest producers. In terms of green hydrogen, produced through water electrolysis powered by renewable energy, Europe is leading the way, with countries like Germany, France, and the Netherlands investing heavily in hydrogen infrastructure. Key players in the hydrogen sector include France's Air Liquide, the United States' Plug Power, and Germany's Siemens Energy.

Other energy storage technologies, such as compressed air ("CAES") and pumped hydro storage, use mechanical methods to store energy. CAES facilities store energy by compressing air into underground caverns, while pumped hydro storage moves water between reservoirs at different elevations. These technologies require specific geological conditions and infrastructure investments but do not rely as heavily on scarce resources. Countries with existing CAES and pumped hydro storage facilities include the United States, Germany, Italy, and Japan.

Carbon Capture, Utilisation, and Storage ("CCUS")

Carbon Capture, Utilisation, and Storage ("CCUS") technologies are vital tools in the global effort to reduce greenhouse gas emissions and mitigate climate change. These technologies capture carbon dioxide ("CO_2") emissions from industrial processes and power plants, store them in geological formations, or utilise them to create valuable products. CCUS implementation relies on advanced materials, engineering expertise, and suitable infrastructure involving various countries and key industry players.[43]

Carbon capture technologies use amines, metal-organic frameworks (MOFs), and membranes to separate CO_2 from industrial exhaust gases. The production of these materials relies on elements like carbon, nitrogen, and metals such as aluminium, zinc, and copper, which are sourced from multiple countries around the world. Regarding engineering and construction expertise, leading engineering firms in the carbon capture sector include Japan's Mitsubishi Heavy Industries, the United States' Fluor Corporation, and Switzerland's ABB Group.

Once CO_2 is captured, it can be stored in geological formations like depleted oil and gas reservoirs, deep saline aquifers, or un-mineable coal seams. The selection of suitable storage sites depends on local geology and infrastructure availability. Countries with significant potential for CO_2 storage include the United States, Canada, Australia, and Norway. In the North Sea, for example, the Northern Lights project is a joint venture between Norway's Equinor, France's Total, and the Netherlands' Royal Dutch Shell, aiming to develop a large-scale CO_2 storage facility.

Carbon dioxide utilisation technologies convert captured CO_2 into valuable products such as chemicals, fuels, and construction materials. This process often relies on catalysts made from elements like platinum, palladium, and iridium. These elements are primarily sourced from South Africa, Russia, and Zimbabwe. Key players in the CO_2 utilisation sector include Canada's CarbonCure Technologies, the United States LanzaTech, and Germany's Covestro.

Renewable Energy Markets

Electric Vehicles are integral to the transition towards a sustainable, low-carbon future. According to the International Energy Agency's ("IEA") Global EV Outlook 2023 report, global electric vehicle sales exceeded 10 million in 2022 and are expected to reach 14 million in 2023, representing a 35% year-on-year increase. China remains the dominant market, accounting for around 60% of global EV sales, followed by Europe and the United States. Emerging markets like India, Thailand, and Indonesia are also experiencing significant growth in EV sales.[44]

Beyond these natural resources, global multinational companies are actively investing in the EV industry and expanding their supply chain worldwide. For example, Elon Musk's Tesla announced in April 2023 that it plans to build a battery factory in Shanghai to produce Megapack energy storage systems. Not only does this underscore the company's efforts to strengthen its global market position, but also its deepening engagement with China. Interestingly, Tesla's announcement comes as Washington calls for American tech firms to reduce their reliance on Chinese manufacturers.[45] Global multinationals, such as Tesla, play a significant role in the EV industry, shaping the production landscape and supply chain dynamics. Its influence in shaping consumer perception and market growth is evident in the increasing global adoption of EVs.

Table 2. Snapshot of Renewable Materials—Top Country Production and American Net Import Reliance.

Material	Use in the Renewable Energy Sector	Top Country by Approx. % of Global Production (2022)	American Net Import Reliance as % of Apparent Consumption (2022)	Primary Import Source (2018-2021)	Importance to American National Defence and Energy Security[1]
ALUMINIUM	Solar Panels Electric vehicles Wind turbines	China 58%	54	Canada	Critical
ARSENIC	Solar Panels	Peru 46%	100	China	Critical
COBALT	Electric Vehicle batteries Renewable energy storage	DRC[2] 68%	76	Norway	Critical
COPPER (REFINED)	Geothermal energy technology Renewable energy storage	China 42%	45	Chile	-
GALLIUM	Electric Vehicles Solar panels	China 98%	100	China	Critical
GERMANIUM	Electric vehicles, solar Panels	China 68%	>50	China	Critical
GRAPHITE	Electric vehicle batteries	China 65%[3]	100	China	Critical
INDIUM	Solar Panels	China 59%	100	Republic of Korea	Critical
LITHIUM	Electric vehicle batteries	Australia 47%	>25	Argentina	Critical
MANGANESE	Electric vehicle batteries Renewable energy storage	South Africa 36%	100	Gabon	Critical
NICKEL	Electric vehicle batteries	Indonesia 49%	56	Canada	Critical

	Renewable energy storage				
RARE EARTH ELEMENTS	Wind Turbines Electric Vehicle batteries	China 70%	>90	China	Critical
SILICON	Solar panels	China 68%	32	Russia	-
SILVER	Solar Panels	Mexico 24%	79	Mexico	-
STEEL AND IRON	Geothermal energy technology	China 52%	14	Canada	-
TELLURIUM	Solar Panels	China 53%	>75	Canada	Critical

Source: United States Geological Survey Mineral Commodity Summaries 2023.

[1]According to the US Geological Survey list of classified "Critical Minerals" published in 2022.

[2]China leads the world in refined cobalt production at 70% of total global supply, owning 15 of 17 industrial cobalt operations in the DRC.

[3]Including the refining of battery-grade raw graphite, China controls 80% of global production.

Conclusion

As is evident from the data, China plays a dominant role in supplying silicon (65% of global production), aluminium (55%), and rare earth metals (70% in 2022). The United States, Russia, and Brazil contribute significantly to silicon production, while Mexico, Peru, and China are top silver producers. India, Japan, and the United States follow China in steel production, with copper primarily sourced from Chile, Peru, and China. These resources are essential for the efficient operation of renewable energy technologies and underline the interconnected nature of the global supply chain.

From the analysis, several conclusions emerge. First, the global supply chains underpinning the net zero transition are complex and interconnected. They involve numerous countries and key industry players. As we transition, fostering better resource management, supply chain resilience, and global cooperation is essential.

Second, if developed countries pursue net zero targets without sufficient diversification or domestic industrialisation, the West's reliance on unstable or undemocratic regimes or regions will also grow. While developed countries have diversified their market access, China dominates global supply chains in key areas. Promoting responsible sourcing and production practices is crucial to mitigate these risks and ensure the long-term sustainability of the net zero transition.

Finally, understanding the key sectors, resources, and industrial processes involved in the net zero transition equips stakeholders with the knowledge to make informed decisions supporting green technologies' growth and sustainability. By examining the nodal points in broader global supply chains and the role of key players and multinationals, the analysis in this chapter endeavours to guide policy and strategic planning.

As the world moves closer to achieving net zero emissions, it becomes increasingly important for policymakers and stakeholders to understand and address the geopolitical risks and potential supply chain disruptions that may arise from such heavy reliance on a single country. By doing so, they can develop more resilient and diversified supply chains, reduce the risk of geopolitical tensions, and promote a more secure and sustainable energy future.

With the foundation laid in this chapter, the following chapter will delve deeper into the vulnerabilities of diversifying supply chains in the net zero transition. By examining potential supply chain disruptions, regional tensions, and other implications of this dependency, the next chapter aims to provide valuable insights and recommendations for policymakers, industry leaders, and stakeholders to mitigate these risks and promote a more robust and sustainable global transition to a low-carbon economy.

Geopolitical Risks and Vulnerabilities in the Rare-Earth Elements Supply Chain: A Strategic Analysis

The previous chapter explored the escalating demand for rare-earth elements as liberal democracies accelerate toward net zero economies. As we have seen, this surge in demand for rare-earth elements remains reliant on emerging peer competitors like China or often unstable regions. The West remains exposed to the possibility of supply disruptions, deepening technological dependence, and the political capacity of hostile states to leverage that dependence for greater global power in the context of an emerging multipolar world order.

As Russia's ongoing war in Ukraine and heightened geopolitical tensions over Taiwan underscore, understanding the dimensions of this strategic dependence is critical. This chapter unpacks these vulnerabilities, offers strategic insights, and analyses geopolitical trends for policymakers and thought leaders.

Geopolitical Risks and Supply Chain Vulnerabilities

The West's primary vulnerability in the context of its net zero ambitions is that China currently dominates the global rare earths supply chain. The 2023 US Geological Survey's Minerals Commodity Summaries report concludes that production is "highly concentrated (50% or more) in a single country, of which five critical minerals had 80% or more of global production dominated by one country, and 17 (including 14 lanthanides) with 70% to less than 80% of global production dominated by one country." The United States is "100% net import reliant for 12 of the 50 individually listed critical minerals and more than 50% net import reliant for an additional 31 critical mineral commodities (including 14 lanthanides, listed under rare earths)." China is the leading producer of 30 of the 50 critical minerals, including 14 lanthanides. The report's data shows that although the United States produces 250 tons of rare-earth elements domestically, it imports a staggering 9,300 tons yearly (over 97% of its needs). China's production capacity is 210,000 tons, representing 70% of the global capacity of 300,000 tons.[46]

Rare Earths Monopoly: Soaring Demand and Future Dynamics

The market demand for rare-earth elements is projected to grow from $2,831.0 million in 2021 to $5,520.2 million in 2028, with a compound annual growth rate ("CAGR") of 10.0% during 2021-2028.

The technologies at the heart of the net zero transition drive this growth.[47] This also occurs in the historical context of a doubling demand for rare earths in the 15 years leading up to 2021, reaching 125,000 tonnes annually. From 2023 through 2040, global demand for neodymium ("NdFeB") magnets will increase at a CAGR of 7.5%, bolstered by double-digit growth in energy transition-related sectors.[48] Looking to the future, the global permanent magnet market is expected to grow from $34.4 billion in 2021 to $54.1 billion by 2026, at a CAGR of 9.5% during the forecast period.[49] However, other regions, such as the European Union, face challenges in meeting future demand due to limited domestic manufacturing capacity, high import dependency, and rising geopolitical tensions. A leading international business intelligence firm concluded: "that global undersupply of NdFeB alloy and powder will amount to 60,000 tonnes annually by 2030 and 246,000 tonnes annually by 2040."[50]

If we take the European Union alone, its demand for rare-earth elements will grow significantly as EV production and sales increase. Approximately 95% of all-electric vehicles use traction motors containing rare earths. Global usage from this sector is predicted to rise from 5,000 tonnes in 2019 to 70,000 tonnes annually by 2030 (a staggering 1,300% increase). By 2030, the EU27 mobility and automotive sector is projected to grow to about €400 billion and create six million jobs, all of which could be at risk due to potential disruptions in magnet supply.[51]

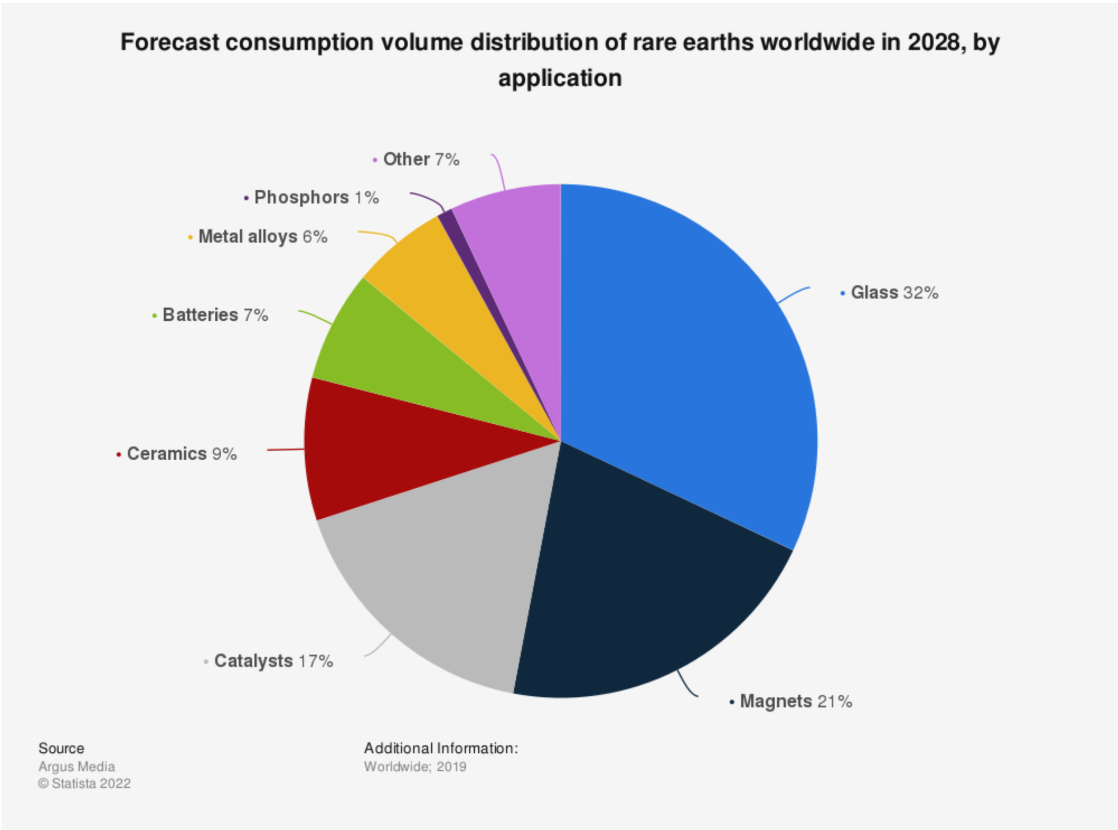

Figure 6[52]

Concentrating on its current monopoly power, China approved the merger of three state-owned enterprises in 2021, creating the world's second-largest rare earths producer, China Rare Earths. This new entity accounts for 30% of China's total rare earth metals production and 60-70% of its heavy rare earth metals production. The newly formed entity will exert more control across the value chain, from extraction to transaction, allowing the Chinese government greater oversight. The merger appears to be initiated from Beijing, supported by local officials, and the new group will be headquartered in Ganzhou, Jiangxi province, a hub for rare earth processing. The group's leadership structure indicates a close alignment with central government authorities, suggesting a robust regulatory alignment. With the formation of this group, China aims to further establish itself as a strategic provider of rare-earth elements globally and enforce stricter rules concerning production and exports.[53]

It is important to note that China's influence is most pronounced in the heavy rare earths sector, a strategically important niche segment despite its relatively small share in overall demand.[54] Heavy rare earths like dysprosium and terbium are indispensable for magnetics and military equipment, making them invaluable to the West. China and Myanmar are responsible for most global heavy rare-earth elements production. According to Chinese customs data and expert estimates, Myanmar is now China's single largest source of heavy rare earths, making up nearly half of the supply.[55] These elements, distinguished by their higher atomic numbers than light rare earths, are essential for shielding the most potent rare earth magnets from high temperatures.

China is a unique nation with the ability to process heavy rare earths. As a result, rare earths, especially heavy ones, mined outside China must be exported there for processing and integration into value chains. Therefore, the popular emphasis on discovering non-China rare earth deposits as a primary solution to potential shortages overlooks a significant aspect: diversification also necessitates the creation of non-China processing, separation, refining capabilities, and supply chains.[56] This monopoly was brought into sharp relief when, in July 2023, China announced export restrictions on gallium and germanium products, citing national security concerns. This move, seen as a response to U.S. technology curbs, remain crucial for computer chips and other components.[57]

As of 2022, China accounted for 85% of rare earth processing worldwide, 70% of the global rare earth production and 92% of rare earth magnet production globally.[58] It has also accumulated more rare earth patents than the rest of the world combined, further solidifying its position in the industry.[59] China has also increased its annual quota for rare earth mining output by 25% to a record high of 210,000 tonnes for 2022. This marks the fifth consecutive quota increase, with the smelting and separation quota also raised by 24.7%. Moreover, China dominates the processing of rare-earth ores from various countries, including the United States.[60]

Critical mineral	United States: Primary production	United States: Secondary production	United States: Apparent consumption	United States: Net import reliance as a percentage of apparent consumption	United States: Primary import source (2018–21)	World: Leading producing country	World: Production in leading country	World: Percentage of world total	World: World production total
Aluminum (bauxite)	W	—	[2]2,900,000	>75	Jamaica	Australia	100,000,000	26	[3]380,000,000
Antimony	—	4,200	[4]27,000	83	China[5]	China	60,000	55	110,000
Arsenic	—	NA	[6]5,300	100	China[5]	Peru	[7]28,000	46	[7]61,000
Barite	W	—	W	>75	China[5]	India	2,600,000	33	[3]7,900,000
Beryllium	180	NA	180	1	Kazakhstan	United States	180	64	280
Bismuth[8]	—	80	2,000	96	China[5]	China	16,000	80	20,000
Chromium	—	100,000	590,000	83	South Africa	South Africa	18,000,000	44	41,000,000
Cobalt	800	1,900	7,800	76	Norway	Congo (Kinshasa)	130,000	68	190,000
Fluorspar	NA	—	500,000	100	Mexico	China	5,700,000	69	8,300,000
Gallium	NA	NA	[2]18	100	China	China	540	98	550
Germanium[8]	NA	W	[6]30	>50	China	China	NA	NA	NA
Graphite (natural)	—	NA	72,000	100	China[5]	China	850,000	65	1,300,000
Indium[8]	—	NA	[6]160	100	Republic of Korea	China	530	59	900
Lithium	W	NA	[6]3,000	>25	Argentina	Australia	61,000	47	[3]130,000
Magnesium[8]	W	37,000	[2]50,000	>50	Israel	China	900,000	90	[3]1,000,000
Manganese	—	—	890,000	100	Gabon	South Africa	7,200,000	36	20,000,000
Nickel	18,000	W	[9]220,000	56	Canada	Indonesia	1,600,000	48	3,300,000
Niobium	—	NA	7,600	100	Brazil	Brazil	71,000	90	79,000
Palladium	11	40	68	26	Russia	Russia	88	42	210
Platinum	3	11	42	66	South Africa	South Africa	140	74	190
Rare Earths (compounds and metals)[10]	250	NA	9,300	>95	China[5]	China	210,000	70	300,000
Scandium	—	—	NA	100	Europe	China	NA	NA	NA
Tantalum	—	NA	1,200	100	China[5]	Congo (Kinshasa)	860	43	2,000
Tellurium[8]	W	—	W	>75	Canada	China	340	53	[3]640
Tin	—	18,000	43,000	77	Peru	China	95,000	31	310,000
Titanium (metal)[8]	W	W	[3]28,000	>95	Japan	China	150,000	58	[3]260,000
Tungsten	—	W	W	>50	China[5]	China	71,000	85	84,000
Vanadium	—	4,400	9,500	54	Canada	China	70,000	70	100,000
Yttrium	NA	—	1,000	100	China[5]	China	NA	NA	NA
Zinc[8]	[11]220,000	([11])	910,000	76	Canada	NA	NA	NA	NA
Zirconium (ores and concentrates)	<100,000	NA	<100,000	<50	South Africa	Australia	500,000	36	[3]1,400,000

NA Not available. W Withheld to avoid disclosing company proprietary data. — Zero.

Figure 7

Source: Survey, U. S. G. (2023). USGS Publications Warehouse. *Mineral Commodity Summaries*. https://pubs.usgs.gov/publication/mcs2023.

Rare Earth Acquisitions: China's Path to Global Influence

China's dominance in the rare earths sector is also underscored by its global acquisitions. China is a major player in the mining and processing rare-earth elements in Africa and has invested heavily in providing debt to African countries. Before the Ukraine crisis, Russia also aimed to expand its African influence using Private Military Companies (PMC) operations. At the same time, China and Russia both focused on mining and processing rare-earth elements in Northern and Western Africa.

China's regime-making capacity, the ability to use its investments and relationships to structure recipient states' foreign and domestic policy preferences, is a crucial aspect of its global influence. Through strategic acquisitions, China can shape the policies and priorities of other countries, ultimately benefiting China's interests and objectives. One prominent example is the Belt and Road Initiative ("BRI"), a massive infrastructure and investment project spanning over 60 countries. By financing and constructing infrastructure projects, China can secure support for its regional and global ambitions and potentially shift the orientation of these countries towards a more Sino-centric world order.

Between 2000 and 2012, before the launch of the BRI, China allocated around $32 billion per year to foreign development finance, while the first five years of the BRI saw an average of $85.4 billion spent annually. By 2020, the total value of China's Belt and Road projects had exceeded $4 trillion. In 2021, total Chinese investment in countries of the BRI amounted to around $59.5 billion.[61]

As of October 2021, Chinese banks account for around 20% of all African loans, mainly in strategic or resource-rich countries. In 2019, Africa's annual borrowing was estimated at $7.6 billion, while Russia has mainly employed the Wagner Group to exert influence on the continent.[62] Between 2000 and 2019, Chinese financiers committed $153 billion to African public sector borrowers. By 2020, sub-Saharan Africa's total external debt stock had risen to $702.4 billion, compared to $380.9 billion in 2012, with China being a significant creditor in the region (an 84% increase in eight years). In addition to Africa, China has also been investing in Latin American mineral resources. For example, in Brazil, Chinese firms like Ningbo Zhoushan have signed deals with Brazilian mining giant Vale to export iron ore to China for processing.[63]

China and Russia are also exploring opportunities in Eurasia, with the Russian government pledging over $1.5 billion to domestic mineral projects, aiming to become a rare-earths leader by 2026. In contrast, China's strategy in Eurasia focuses on investing in mining operations in Mongolia.[64]

China's focus on technology and innovation is also evident in its state-led strategy of actively acquiring and absorbing technology from abroad and outpacing the United States. It has been documented that the Chinese government has repeatedly courted and invested in foreign businesses to steal intellectual property ("IP"). Reports suggest that Chinese IP theft has cost the United States between $225 billion to $600 billion a year, leading to FBI Chief Christopher Wray arguing that this represents "one of the largest transfers of wealth in human history."[65]

Human rights concerns are also important. For example, the China Strategic Risks Institute report exposes the alleged widespread use of state-sponsored forced labour in China's Xinjiang region, a practice affecting Uyghurs and other minorities. Xinjiang, accounting for 45% of global solar-grade polysilicon, is intimately linked with global solar power supply chains. The report predicts China's solar panel manufacturing share to rise to 95% by 2025, presenting ethical and strategic challenges for green energy transition and advocating for stronger modern slavery legislation.[66]

State-owned enterprises ("SOEs") are also crucial to China's economy and global influence. SOEs accounted for over 60% of China's market capitalisation in 2019 and generated 40% of China's GDP in

2020. These companies compete in critical technologies such as robotics, artificial intelligence, and biotechnology, dominating key industries and propelling private firms into the global market. State ownership is widespread in strategic sectors like energy, telecommunications, and banking, with 71% of China's Fortune 500 companies being state-owned.[67]

In summary, China's capacity to shape global policy through investments and relationships is vital to its international influence. By prioritising technology, supporting state-owned enterprises, and harnessing its rare earths market dominance, China has established a strategic network to further its regional and global goals. Yet, this is only one aspect of the story; the profound implications of rare-earth elements in cutting-edge military technologies are crucial for comprehending their effect on evolving power dynamics and the larger world order. We now focus on this critical dimension, exploring the gravity of China's rare earths dominance concerning Western military capabilities.

Rare Earths and the Evolution of Military Technologies

Beyond China's dominance in producing rare-earth elements, processing and patenting, all central to the net zero transition, there is a critical strategic dimension to the current imbalance of supply chains that extends to military technology. For example, the cutting-edge F-35 Lightning II, a family of state-of-the-art all-weather stealth multirole fighters, is designed and built by Lockheed Martin. Rare-earth elements are crucial in producing the F-35's advanced technology, including radar systems, guided missiles, and other electronic components. Components such as powerful magnets and sensors require rare-earth elements like neodymium, dysprosium, and terbium.

The reliance on rare-earth elements in producing the F-35 and other advanced military technologies underscores their strategic importance for American national security and, by extension, the liberal world order under the United States' military superintendence. The worsening relations between the United States and China over Taiwan further exacerbate the situation. The United States supports Taiwan through the 1979 Taiwan Relations Act, approving significant arms sales, engaging in joint military exercises, and training Taiwan's military. However, the longstanding American policy of "strategic ambiguity" regarding its response to a potential Chinese invasion of Taiwan has recently been questioned, with some lawmakers pushing for a more explicit commitment.[68]

If China were to limit or disrupt the supply of critical materials, it could significantly impact the production and maintenance of the F-35 and other military equipment, potentially affecting the readiness and capabilities of Western armed forces. This is especially pertinent given these growing tensions over Taiwan. A January 2022 bipartisan US Senate bill endeavoured to address these supply chain issues by preventing defence contractors from purchasing rare earths from China by 2026. The goal was to use the Pentagon's weapons purchases as leverage to encourage American domestic rare earth production.

Nevertheless, the Pentagon was forced to issue a waiver due to the heavy reliance and supply chain imbalances later that year. Chinese officials have not overlooked this fact. A senior official of a state-owned rare-earth enterprise in Ganzhou stated that China is the "only country in the world that has developed the ability to extract samarium and cobalt rare-earth metals, which means the middle product samarium oxide is almost 100 per cent made in Chinese factories. We also account for over 70 per cent of the final product of samarium-cobalt rare-earth magnets. How can Washington take out Chinese rare-earth products from its jets in such a scenario?"[69]

Underlining this imbalance and perhaps signalling future trends in 2023, China placed Lockheed Martin and a Raytheon Technologies unit on an "unreliable entities list" over arms sales to Taiwan, banning them from imports and exports related to China in its latest sanctions against American companies. A commentary published by state-owned Chengdu Radio & Television stated that China could freeze the two companies' mainland assets and forbid them from purchasing Chinese rare earths. It explained: "The latest sanction is a warning to Lockheed Martin. According to the Anti-Foreign Sanctions Law, we have the right to freeze its mainland assets." The commentary continued: China could also take "other necessary steps, such as banning rare earth exports to Lockheed Martin … Although the United States also has rare earths, it will take time to develop its supply chain while China still owns the key processing technology of the minerals."[70]

The United States is thus in an invidious position. Its F-35s would be crucial to Taiwan's defence. China's limited number of 5th-generation J-20 aircraft are not designed for ship take-offs and landings, making them vulnerable to F-35s.[71] The potential forward positioning of American assets and allies, including F-35s, in the Pacific could counter a fast-advancing Chinese attack on Taiwan. However, those F-35s are reliant on Chinese-supplied rare-earth elements. A critical question emerges: Would China continue to supply rare-earth elements for the United States' F-35s as those same jets conduct operations against Chinese assets?

Beyond this, advanced technologies like 5G, artificial intelligence ("AI"), and quantum computing are becoming crucial components of national security strategies and rely on rare-earth elements.

5G technology, the next generation of wireless communication, is expected to revolutionise how people and devices connect, enabling faster data transmission, increased network capacity, and reduced latency. The widespread adoption of 5G technology has significant implications for national security. It can enhance the efficiency of military communication systems, improve situational awareness on the battlefield, and enable the development of new defence applications. Moreover, artificial intelligence (A.I.) systems rely on large amounts of data and powerful computational resources made possible by rare-earth elements.[72] For example, neodymium and dysprosium are used in the magnets of high-performance electric motors in AI-powered drones. At the same time, lanthanum, cerium, and yttrium are essential in manufacturing advanced optical lenses and sensors. Quantum computing is an emerging technology that has the potential to revolutionise computing and cryptography. By exploiting the principles of quantum mechanics, quantum computers can solve complex problems exponentially faster than traditional computers. Rare-earth elements, such as europium and erbium, are used in developing quantum computing technologies due to their unique magnetic and optical properties. Quantum computing has significant national security implications, as it could potentially break existing encryption algorithms, disrupt secure communications, and enable advanced simulations for defence applications.[73]

If the West and the United States could not secure sufficient rare-earth elements to power these advanced technologies, it could have severe consequences for national security, leading to a slowdown in innovation in defence applications, compromised communication systems, and decreased military capabilities. In a worst-case scenario, this would result in losing technological and strategic advantages in the context of a shifting distribution of global power. Thought leaders and policymakers must remain cognisant of these strategic issues in the broader context of the net zero transition and supply chain issues.

Conclusion

Beyond the United States, Japan significantly depends on China for rare-earth elements, importing 58% of its supply. This dependence leaves Japan vulnerable to potential manipulation by Beijing, as demonstrated by a temporary export ban on rare-earth elements to Japan in 2010. In response, Japan has been diversifying its sources of rare earths and reducing its reliance on China, including investing in non-Chinese projects and stockpiling rare metals. Europe is also highly dependent on China for its rare-earth elements, with the European Union ("EU") importing around 98% of its needs from China.[74] As we will see in the next chapter, Europe is also working to reduce its reliance on Chinese rare-earth supplies and secure alternative sources, such as Sweden's Kiruna mine. However, while the West is working to diversify rare-earth supply chains, a massive surge in demand occurs as the transition to net zero gathers pace.

The increasing demand for rare-earth elements drives global competition for access to these critical resources and exacerbates already imbalanced supply chains. China's dominance in the rare earths market has significant implications for the net zero transition, industrial development, global politics, and potential conflict.

SOEs compete in crucial industries like robotics, AI, and biotechnology and are critical in China's economy and global influence. China's near-monopoly on producing, processing, and patenting rare-earth elements gives it a strategic advantage, allowing it to exert significant influence over global supply chains. The Belt and Road Initiative's massive infrastructure and investment project extends its global reach with investments in strategic and resource-rich countries in Africa, Latin America, and Eurasia.

Rare-earth elements are crucial in advanced military technologies, including the F-35 Lightning II stealth fighter jet, underscoring their strategic importance for national security. The worsening relations between the United States and China over Taiwan further exacerbate the situation. In addition to military applications, rare-earth elements are essential for developing emerging technologies like 5G, AI, and quantum computing. These have significant national security implications and could potentially disrupt secure communications and defence applications and help shape tomorrow's industrial future.

Liberal democracies, particularly the United States, are grappling with the challenge of addressing these imbalances and securing access to critical resources in the context of the net zero transition. The next chapter will explore the strategies and approaches employed to address these challenges to mitigate the strategic risks we have examined in this chapter.

Strategies for Risk Mitigation and Supply Chain Resilience

This chapter dissects the economic, strategic, and geopolitical intricacies underpinning the international rare earths landscape.

First, we scrutinize China's strategic "rubber banding" approach to export quotas, which has enabled it to deftly manipulate global supply and demand dynamics. This chapter unpacks the consequences of this strategy on global rare earths pricing and availability and how it has strained economies and industries reliant on these strategic minerals. Second, we examine the predicament of the few significant non-Chinese rare earths producers, particularly Lynas Corporation. China's dominance and strategic oversupply of certain rare-earth elements have inadvertently impacted Lynas' profitability and business stability. Third, we explore the "Chinese subsidy" as a dual-edged sword. While such subsidies have allowed global industries to benefit from affordable rare-earth elements, they have distorted global markets, curbed industrial innovation outside China, and intensified global dependence on China's rare earths supply. Lastly, we delve into the strategic responses of nations grappling with this monopolistic scenario, focusing on approaches such as stockpiling and alliance formation. Through these counterstrategies, we discern the complex geopolitical calculations and initiatives shaping global supply chains in the context of the net zero transitions.

Navigating these multifaceted dynamics, this chapter offers an in-depth exploration of the global rare earths market, where an abundance of resources paradoxically begets scarcity, and the pursuit of technological advancement is inherently tied to geopolitical manoeuvring.

Diversification

Across the liberal democracies, there has been a concerted effort to diversify global supply chains in response to the dependencies we examined in the previous chapter. There is growing recognition of the need to “de-risk” (as opposed to “decouple”) Western energy supplies from ever-increasing dependence on China. In May 2023, G7 countries and the European Union affirmed support for a “de-risking” strategy, which identifies areas of collaboration with China and areas for internal cooperation instead, such as in sensitive technological sectors and supply chains. The nature of risk mitigation strategies largely will depend on each country's economic situation and resource potential.[75] As the President of the European Commission, Ursula von der Leyen, emphasised, “de-risking” does not entail “cut[ting] economic, societal, political or scientific ties.” Still, it does require a realistic assessment of how to rebalance the European Union’s trade relationship to protect the economy, generate sustainable energy, and enhance national security.[76]
This chapter investigates ways in which developed countries are diversifying their supply chains and taking steps to pursue a de-risking strategy.

United States

Given the United States’ primacy, one of the most significant steps was taken in 2021 when President Joe Biden issued Executive Order 14017, titled “America’s Supply Chains.”[77] This Order mandated a comprehensive review of vulnerabilities in the United States’ rare earths supply chain and identified an over-reliance on foreign sources, particularly China, as a potential threat to national security.

In response, significant investments have been announced to boost the domestic production of critical minerals. For example, one of the US’s leading rare earths companies, MP Materials, received funding to establish a domestic supply chain for heavy rare-earth elements and is investing $700 million in constructing a new permanent magnet factory in Fort Worth, Texas, to ”onshore” production of rare-earth permanent magnets to the United States. This initiative is part of the company’s vertical integration strategy, starting with the Mountain Pass mine in California and encompassing the entire supply chain.[78]

Similarly, Berkshire Hathaway Energy Renewables announced an investment in sustainable lithium production from geothermal brine, which has the potential to produce a significant amount of lithium per year. This novel approach to lithium extraction aims to meet the increasing demand for lithium, particularly in the EV and energy storage sectors. In spring 2023, they also plan to initiate the construction of a demonstration facility in Imperial County, California. Once fully operational, it could yield up to 90,000 metric tons of lithium annually.[79]

More targeted initiatives are also underway to promote the domestic production and recycling of rare-earth elements. Aside from the MP Materials Mountain Pass mine, UCore Rare Metals Inc. is also developing the Bokan mine in Alaska. These companies, along with others such as USA Rare Earths, are actively working to establish domestic sources for rare-earth elements in the United States and thus reduce dependence on foreign supply. Redwood Materials has partnered with Ford and Volvo to recycle batteries and extract lithium, cobalt, nickel, and graphite. This partnership aims to create a closed-loop battery supply chain, reducing waste and promoting sustainability.[80]

Aside from rare earths onshoring, the United States also invests in recycling technologies to reduce mining impacts and increase supply chain resiliency. Companies like Redwood Materials are partnering with automakers to recycle batteries and extract critical materials. The Department of Energy also funds a project to recover rare-earth elements and other critical minerals from coal ash and mine waste.[81]

Importantly, the United States is also reforming its mining laws and regulations, including prioritizing permits for critical minerals and strengthening stockpiling activities for a clean energy transition and national security. The aim is to make it easier for companies to mine and process rare-earth elements domestically. It is a step in the right direction of dynamic and response regulatory reforms to free up barriers to market entry. Similarly, initiatives are being taken to attract major companies to domestic sourcing critical minerals. For example, new rules released in March 2023 by the US Treasury tie tax battery sourcing requirements for EV tax credits. The mandate specifies a minimum percentage of battery components produced or assembled in North America and critical minerals sourced from the United States or trade agreement countries. The guidance is designed to help boost EV sales and, crucially, help shift automaker supply chains to domestic production and supply.[82]

The United States is thus taking a multi-pronged "onshoring" approach to diversify its rare earths supply chains. This includes policy measures, investment in domestic production, the promotion of recycling, research and development into new sources of rare-earth elements, and reforming mining laws and regulations.

European Union

Beyond the United States, the European Green Deal is the European Union's blueprint for achieving net zero greenhouse gas emissions by 2050 and is helping drive the net zero agenda forward. Approved in 2020, the deal encompasses several sectors, including climate, energy, transport, and taxation. It plans to review existing laws for their climate merits and introduce new legislation on the circular economy, building renovation, biodiversity, farming, and innovation. Targets include reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, and achieving full climate neutrality by 2050.[83] To bolster this effort, a significant portion of the NextGenerationEU Recovery Plan, originally developed to address the economic impacts of the COVID-19 pandemic, is now being allocated to finance the European Green Deal with one-third of the €1.8 trillion investments from the NextGenerationEU Recovery Plan, and the EU's seven-year budget (2021-27), helping to sustain the EU's Green Deal.

The European Union has recognised the need for supply chain diversity. Thierry Breton, EU Commissioner for Internal Market has argued that "The Commission's in-depth review of critical supply chains and key technologies has highlighted the EU's high level of foreign dependency on inputs required for our green and digital transition and our continent's resilience.". He continued, explaining that the EU "depends on others – mainly China – for the import of permanent magnets, as well as the rare-earth elements they are made of."[84] In 2022, European Commission President Ursula von der Leyen also emphasised the growing importance of lithium and rare earths, that are "already replacing gas and oil at the heart of our economy. By 2030, our demand for those rare earth metals will increase fivefold." This, she argued, is a "good sign because it shows that our European Green Deal is moving fast." However, von der Leyen also argued that one country dominates the market where almost "90 % of rare earths and 60 % of lithium are processed in China."[85]

In mitigating this, one of the EU's pivotal initiatives was the establishment of the European Raw Materials Alliance ("ERMA") in September 2020. ERMA aims to secure and diversify the supply of sustainable raw materials across Europe and forms part of the Action Plan on Critical Raw Materials, a broader European Green Deal component. With the Rare Earth Magnets and Motors cluster as its primary focus, ERMA is designed to identify and address barriers, incentivise investment opportunities and build capacity across the raw materials value chain, from mining to waste recovery.

Proposed in March 2023, the EU's Critical Raw Materials Act is designed to introduce legislation that ensures access to a secure, diversified, affordable, and sustainable supply of critical raw materials, boosts the resilience and diversification of EU supply chains, and sets benchmarks and targets for domestic production capacities, supply chain diversification, and recycling. Its key goals are to simplify administrative procedures, support access to finance, shorten timeframes for strategic projects, and encourage exploration of geological resources. As of the time of writing, the proposed Regulation has yet to undergo discussion and agreement by the European Parliament and the Council, but it strongly signals the direction of travel.[86] In short, the EU remains collectively deeply dependent on China for its rare-earth elements. However, it is now moving towards establishing a regulatory and financial incentive structure to help build greater resilience in its supply chains for the net zero transition.

United Kingdom

Similar to the United States and the European Union, the British government has been proactive in its initiatives to diversify the supply chain of rare-earth elements and support research that facilitates the country's transition to net zero carbon emissions. A key aspect has been the announcement of the UK's Critical Minerals Strategy. Launched in 2022 to enhance resilience and diversify supply chains for critical minerals, its key initiatives involve maximizing domestic production, rebuilding mining skills, and promoting research and development. The strategy also aims to accelerate a circular economy for critical minerals, emphasizing the importance of resource recovery, reuse, and recycling.[87]

The United Kingdom's 2023 Critical Minerals Refresh delineates strategic initiatives to create resilient and diversified supply chains, promote industry growth, and foster investment in the critical minerals sector. A cornerstone of this approach is developing a risk framework designed to monitor and mitigate critical mineral supply risks across diverse sectors. This framework is expected to support businesses in making decisions and maintaining a stable supply of critical minerals.[88] Complementing this, the British government is preparing to publish the UK Supply Chains and Import Strategy, which will outline the country's priorities and approach to critical imports, enabling businesses to build robust strategies around these guidelines.

To enhance the domestic production capabilities, the British government is assessing its potential for critical minerals extraction and is providing support for mining and refining activities. This is further supplemented by efforts to facilitate critical mineral companies navigating governmental funding opportunities and liaising with relevant funding organisations.

Research plays a significant role in this plan, with the Critical Minerals Innovation Centre ("CMIC") set to publish studies focusing on material requirements for specialised alloys in the aerospace, defence, and hydrogen economy sectors. Additionally, there are plans to explore the United Kingdom's potential for extracting and producing battery materials.[89]

To promote investment in the sector, the government is also creating a foreign direct investment proposition to encourage investment in the United Kingdom's critical minerals project, with reforms being proposed to streamline the planning system for future critical minerals projects.

One notable project on the horizon is the construction of the United Kingdom's first rare-earth materials processing facility by Pensana Rare Earth. Located at Saltend Chemicals Park in Humber, this facility is projected to be the world's first independent and sustainable rare earth separation plant, with an estimated production of 5% of the global magnet metals by 2024. Moreover, several projects are being funded through UKRI's Supply Chains for NetZero competition. One such project, led by Ricardo UK Ltd, is developing sustainable electric motors that require significantly fewer rare-earth elements per motor compared to current models.

Broader International Coordination

Alongside country-specific initiatives, the United States and several other key partner countries established the Minerals Security Partnership ("MSP"). This international initiative aims to bolster the supply chains for critical minerals. It includes Australia, Canada, Finland, France, Germany, Japan, South Korea, Sweden, the United Kingdom, the United States, and the European Union.[90] The partnership encourages enhanced information sharing between the participating countries and the implementation of Environmental, Social, and Governance ("ESG") standards in critical mineral projects.

It is also worth noting the role played by other leading powers, most notably Australia, that has sought to position itself as a key player in the western supply chain of rare-earth elements.[91] At the G7 in May 2023, Australian rare earth miner Iluka Resources and the United States announced a deal that builds on the centrality of Australia's Lynas Rare Earths to rare earths production.[92] Lynas is the only major producer of separated rare earths outside China and has partnerships with other companies to provide key processing inputs. Lynas has reportedly struck a deal with BHP's resurgent nickel business to supply it with sulphuric acid, a key input in the processing of rare earths. Lynas has also expanded its processing capabilities, with facilities in various locations, such as its cracking and leaching facility outside Kalgoorlie in Western Australia. It also now has an advanced rare earths separation facility in Malaysia and a $170 million contract with the US Department of Defence to build a rare earths refinery in Texas.[93]

Countering Market Distortions: The "China Subsidy"

In the 1990s, China declared the production and processing of rare-earth elements a strategic priority. It sought to prevent foreign investment in its rare earths sector and coordinate between the government and rare earths producers to limit production and exports. As such, it is important to understand that China's dominance in the global rare-earth elements market is not an accident but by design and has had a range of market-distorting effects.

While the government now focuses more on developing downstream capabilities, a shift from their extractive focus decades ago, rare earths still figure prominently in high-level communique. For example, China's latest Five-Year Plan continues to specify the centrality of rare-earth elements on developing more value-added production, "such as high-end rare earth functional materials, high-purity special steels, high-performance alloys, high-temperature alloys, [and] high-purity rare metal materials."[94] This "joined-up" strategic approach has been underpinned by massive state subsidies and industrial policies that have kept rare earths prices artificially low. This has had several effects and helps explain both the increased political desire for global supply chain diversification and some of the problems these initiatives may face.

First, the "China subsidy" historically has been based on its low levels of environmental regulation that has helped its subsidy regime monopolise the market by domesticating the environmentally damaging effects of processing rare-earth elements. For example, extracting rare-earth elements leaves a substantial environmental impact—generating up to 60,000 cubic meters of waste gas, 200 cubic meters of acid-contaminated wastewater, and over a ton of radioactive waste per ton of produced rare-earth elements.[95] Aside from the environmental costs to China, this subsidy regime has profound global market distortions, not least of which has been the bankruptcy or retreat of competitors who could not match China's subsidy regime. We see this most clearly in China's strategic use of quotas and tariffs on rare earths.

In 2010, a major diplomatic dispute arose between China and Japan following a collision between a Chinese fishing trawler and the Japanese coast guard. Following this, China blocked its rare earths exports to Japan. This temporarily damaged Japanese industries reliant on China's rare-earth elements but also led to significant domestic exploration in Japan and rapid industrial adaptations in the face of China's export choking. Similarly, in 2015, China relaxed export quotas that helped bankrupt Molycorp, one of the United States' leading rare earths processors. China's market flooding not only undercut Molycorp but was left with significant debt. Interestingly, one of Molycorp's unfinished facilities was then taken over by a consortium, including China's Leshan Shenghe Rare Earth Company, that held a 30% non-voting share and exclusive sales rights for Mountain Pass minerals, demonstrating China's strategic influence and continued commitment to global rare earths supply. It also underscored the power of China's subsidy regime and its strategic "rubber banding" in tightening or loosening to distort global markets and either punish interstate rivals or help drive out competition through strategic oversupply.[96]

Second, considering the important dissimilarities in different types of rare earths, Lynas remains the only major miner and processor of rare-earth elements outside of China. We have already examined the centrality of heavy rare earths to modern industrialisation, especially in the military sphere. Chinese subsidies have fuelled China's dominant presence in the market, particularly within the realm of heavy rare earths, causing an imbalance in the availability and pricing of different rare-earth elements. Specifically, subsidies have catalysed an oversupply of lighter rare-earth elements, such as lanthanum and cerium. In its rare earths extraction process, Lynas also yields these lighter elements, leading to a fall in their prices due to excess supply. Despite producing these lighter rare-earth elements, this situation has eroded Lynas' revenue base.

The market dynamics become even more complex considering the growing demand for heavier rare-earth elements. These elements are integral to innovative and sustainable technologies, such as wind turbines and electric vehicles, which, as we have seen, are experiencing substantial growth. The increased demand for heavier rare-earth elements prompts an upswing in their production. However, the extraction and refinement process for heavier rare-earth elements invariably co-produces significantly lighter ones. This co-production escalates the oversupply issue, further devaluing the lighter rare-earth elements and impairing Lynas' profitability.

The dilemma is accentuated by China's heavy rare earths dominance and conscious strategy of 'limit pricing', which undercuts competitors lacking similar refining capacities; a particularly acute problem in limit pricing tends to be more potent in industries with substantial economies of scale. The barriers to entry in such markets are high and are confined to very few companies due to the sizable investments required. Thus, despite profiting from the demand for heavy rare-earth elements, Lynas is disadvantaged by the overabundance and price decline of lighter rare-earth elements—a predicament largely attributable to China's subsidisation. Further, and as examined above, the looming prospect of more countries establishing their own rare earths production facilities threatens to exacerbate the oversupply issue, possibly causing a further price drop. This volatile landscape poses significant challenges for all stakeholders in the rare earths market.

In short, the “Chinese subsidy” has acted as a global subsidy, benefiting industries dependent on rare-earth elements but at a significant and market-distorting cost within the global economy. A critical side effect of this dynamic has been the suppression of industrial innovation outside China, with the incentive to invest in developing efficient and environmentally friendly rare earths processing technologies reduced due to the availability of cheap rare-earth elements from China.

Stockpiling and Forming New Alliances: Strategic Approaches

Given China's strategic market control, the complexity of diversifying the rare earths supply chain has sparked a growing interest in alternative strategies for ensuring rare earths supply security, including stockpiling. This involves creating a reserve of rare-earth elements to counter potential supply disruptions that, in the worst case of potential military conflict, may even see a full cessation of supplies. While not a novel concept, having been employed for strategic and critical materials during periods such as the Cold War, the potential for geopolitical tensions disrupting the supply of rare-earth elements makes stockpiling increasingly appealing today.

How feasible is stockpiling as a strategy for guaranteeing rare earths supply security? While stockpiling rare-earth elements appears to be a straightforward strategy, numerous considerations arise. Firstly, stockpiling entails considerable expenses, from acquiring rare-earth elements to storing and preserving them. Current economic conditions might dissuade governments from dedicating substantial funds to stockpiling. Secondly, stockpiling does not resolve the root issue of dependence on China for rare-earth elements. It offers a stopgap solution in a supply disruption scenario but fails to present a long-term strategy for reducing reliance on China’s rare earths market.

Countries like Japan and the United States are already planning to enhance their rare earth stockpiles. Japan’s International Resource Strategy, announced in March 2020, emphasizes strengthening the stockpiling system for 34 types of rare metals, including rare-earth elements. Meanwhile, the United States maintains a National Defense Stockpile of critical minerals, including rare-earth elements, managed by the Defense Logistics Agency. The increasing concern over China’s rare earth market dominance has initiated a course reversal, with Congress and the Defense Department planning to bolster the National Defense Stockpile through significant investments.

Stockpiling is challenging despite being a practical strategy to alleviate risks associated with foreign rare earths supplies dependence. It demands considerable investments, and the volume required to cushion potential supply disruptions can be immense. Deciding which rare-earth elements to stockpile and in what quantities is also complex, necessitating an intricate evaluation of a country’s industrial needs, geopolitical risks, and market dynamics.

In summary, the lasting influence of Chinese subsidies requires Western countries to take decisive action. Promoting innovation, diversifying supply chains, and encouraging sustainable mining practices are key to rebalancing the rare earths market and reducing dependence on China.

Conclusion

This analysis of the global rare earths market demonstrates the complexity of economic, political, and strategic factors at play. As we have seen, China’s dominant role in the rare earths market, underpinned by robust state subsidies and strategic export quota manipulation, has significantly influenced the availability and pricing of these crucial elements worldwide.

Our examination of the experiences of Lynas Corporation illustrates the considerable challenges facing non-Chinese rare earths producers operating within a market predominantly influenced by China's policies. The combination of an oversupply of light rare-earth elements and market undercutting strategies has undermined Lynas' profitability, highlighting the pervasive market distortions and imbalance caused by China's actions.

Moreover, we have investigated the inherent dilemma in the rare earths market dynamics. As demand for heavier rare-earth elements continues to grow, driven by the expansion of innovative and sustainable technologies, the co-production of lighter rare-earth elements escalates, leading to oversupply and subsequent price decline.

While beneficial for rare earths-dependent industries, China's subsidy regime has suppressed industrial innovation outside of China. It diminishes incentives for investment in developing efficient and environmentally friendly rare earths processing technologies due to the availability of inexpensive rare-earth elements from China.

Lastly, we have considered the potential strategic approaches of stockpiling and forming new alliances to secure rare-earth elements supplies. While stockpiling provides a buffer against potential supply disruptions, it is expensive and does not address the root issue of dependence on China. While challenging, forming new alliances and diversifying supply chains offer more sustainable long-term solutions.

The insights gleaned from this investigation underscore the urgency for Western countries to take decisive action, including promoting innovation, diversifying supply chains, and encouraging sustainable mining practices. These strategies can contribute to a more balanced global rare earths market and reduce the over-reliance on China, promoting a more resilient and diversified global economy.

Balancing State Intervention and Market Forces: Solutions for Rare Earths Dominance and Supply Chain Diversification

The interrelationship between policy frameworks and innovative market solutions is crucial as we navigate the complex realities of global supply chains and the net zero transition.

First, policymakers can encourage market innovation through various forms, such as tax breaks, subsidies, and grants. They can be strategically designed to motivate companies to invest in alternative rare earths sources, pursue research and development into new technologies, and adopt more sustainable practices. By driving competition and innovation through these incentives, the state can catalyse industry-wide shifts and enhance efficiency, all while making strides towards environmental sustainability.

The United States, for instance, has leveraged financing mechanisms, including grants, subsidies, preferential loans, loan guarantees, and other financial incentives to encourage new critical mineral developments. The Infrastructure Investment and Jobs Act modifies the Department of Energy's loan guarantee programme to include projects enlarging supplies of domestically produced critical minerals and recycling technologies. A production tax credit for producers of critical minerals has also been established under the US Inflation Reduction Act, which integrates incentives for domestic mineral production into the electric vehicle tax credit. Similarly, Australia's government has launched an AUD 2 billion Critical Minerals Facility to offer loan guarantees or preferential loans complementing private financing to support projects extracting or processing minerals for export.[97]

Public-Private Partnerships ("PPPs") also offer another avenue for state facilitation. These collaborations represent a unique risk and reward-sharing opportunity, particularly within research and development arenas. By combining state support with the dynamism and risk-taking potential of the private sector, PPPs can stimulate the creation of pioneering solutions. Examples of the strategies adopted in PPPs include green public procurement, carbon contracts for difference, carbon border adjustment, industrial clusters, and climate partnerships.[98] For instance, in London, the Mayor's preferred Accelerated Green pathway, which requires a significant acceleration in action across the city, will be implemented with a proposed £75 billion infrastructure investment by 2030.[99]

Regulatory measures are another potent tool at the state's disposal. Through these, the state can advocate for sustainable business practices such as energy efficiency, waste reduction, or adopting alternative materials. Governments can invest in infrastructure that supports the mining industry, such as roads, ports, and power supply. This can help expedite the development of new mining projects and ensure a smoother flow of materials in the supply chain. For example, the United States is now restructuring its regulatory regimes to stress global supply chain resilience in the longer term over shorter-term "just in time" efficiency gains.[100]

However, changes in regulatory environments are not without risk. For example, whilst the Inflation Reduction Act ("IRA") has shaped the United States' approach towards onshoring and friend-shoring EV supply chains, it has caused tensions with trading partners, including Europe, where there is no free trade agreement between the United States and the European Union. EU leaders view Biden's IRA as overly protectionist and have demanded exemptions with its Green Deal Industrial Plan, including the Net Zero Industry Act and the Critical Raw Materials Act, that aims to bolster EU competitiveness and secure sufficient access to materials for clean energy technology. The European Union is reportedly negotiating a minerals-specific agreement with the United States, like the US-Japan agreement, to mitigate the disadvantages of the lack of a free trade agreement. These developments underline a global regulatory reform effort to foster resilient, diversified supply chains, focusing on boosting domestic capacities and broadening international cooperation.[101]

When performed effectively, these multiple roles of the state can help guide market forces in creating durable solutions to our dependence on rare-earth elements. Simultaneously, they can contribute significantly to our broader adaptation to climate change and efforts to address global supply chain bottlenecks. However, this requires a careful balance, allowing the market the freedom to dictate and innovate while providing the necessary steering and support.

The Power of Markets

In the complex and often perplexing web of issues surrounding the global supply of rare-earth elements, markets offer a resilient solution rooted in economic freedom and innovation. Markets, in their essence, represent a broad array of interactions between multiple entities—individuals, companies, and countries—each with their interests, needs, and ideas.

The "distributed wisdom of markets" denotes the collective decision-making ability of market participants and is crucial in diversifying global supply chains in the transition towards net zero emissions. To adapt supply chains, industries supplying critical materials for the energy transition, such as the metals and minerals sectors, must evolve. Market forces can catalyse this transformation by incentivising companies that diversify and decarbonise their supply chains. For example, major companies like Tesla are exploring material substitution options for long-term-constrained or regionally concentrated materials in EV production.[102]

This aggregated human choice and agency system enables self-regulation and adaptation to changes in a way that top-down, centralised approaches often cannot achieve. It harnesses the collective intelligence of actors, ensuring that a wealth of perspectives and information informs decisions made at any point. The result is a flexible, dynamic market that responds to shifting needs and trends.

Efficient markets, in their essence, are fundamentally democratic. They operate based on voluntary exchange and mutual agreement. Each transaction represents a vote, a choice made by an individual or an entity that reflects their values, preferences, and needs. This democratic system enables self-regulation, adaptability, and resilience to changes in a way that top-down, centralised approaches often struggle to achieve. It harnesses the collective intelligence and wisdom of all actors in the market, allowing decisions to be informed by a wealth of perspectives, experiences, and information. The result is a flexible, dynamic market that can respond to shifting needs, trends, and unforeseen circumstances.

The principle of subsidiarity, which emphasises that decisions should be made as close as possible to the citizen, becomes even more pertinent as we consider the global transition towards net zero emissions. This principle acknowledges the diversity of circumstances across different regions, demographics, and socio-economic groups. The impact of the net zero transition is not homogenous; it varies significantly between rural and urban populations and among those who can afford new technologies versus those who cannot.

Rural dwellers, for example, often must cover longer distances and may not have access to the same infrastructure, like charging stations, as urban dwellers. They also might face different energy needs or have access to utilise additional resources. Urban dwellers, on the other hand, have different lifestyles and infrastructure available, for example, easier access to transportation, and thus, their solutions for energy transition might look different. Even within the context of cities, initiatives such as London's Ultra Low Emission Zones ("ULEZ") can have impacts on those from different socio-economic backgrounds, with those that can afford new electric cars differentially impacted against those that cannot and rely on older and more polluting forms of transportation.

As such, a market-led approach can adapt to these variances in ways that top-down, one-size-fits-all policies often cannot. Market solutions, driven by the needs and capacities of individual actors, are better positioned to address these local realities and make the transition to a low-carbon economy inclusive and equitable.

In the net zero transition context, these market dynamics are crucial. They govern everything from sourcing materials and their production to distribution across various sectors. Market forces, therefore, shape how rare-earth elements are used, the technologies developed to exploit them, and the policies crafted to manage them.

However, the market's dynamism and adaptability also come with a caveat: the risk of overreliance on dominant players, in this case, China. If market participants collectively favour sourcing from one country due to lower costs or higher production capabilities, it could lead to an overdependence that poses strategic risks. This scenario illustrates that markets with self-correcting mechanisms are not immune to imbalances.

Despite these risks, the market's inherent characteristics—competition, freedom of choice, and the capacity for innovation—make it a powerful tool for responding to supply chain concerns while undergoing the net-zero energy transition. Competition drives companies to innovate and find alternatives to conventional sources and processes. Freedom of choice allows consumers to influence the market towards more sustainable practices. And the capacity for innovation paves the way for technological advancements that could reduce our dependence on fossil fuels.

Alliances

As the global community grapples with issues surrounding net zero goals and the intricacies of global supply chains, it is also imperative to consider these within a broader geopolitical transition and the evolving dynamics of world order. The market, in its democratic essence and innovative potential, offers a strategic apparatus for navigating these transitions, empowering nations to adapt, innovate, and thrive amidst changing circumstances. Yet, it is crucial to acknowledge the role of regulation, ensuring that while the market drives growth and technological advancement, it does not foster dependencies that could compromise a nation's strategic interests.

Enter emerging strategic alliances, such as the trilateral security pact between Australia, the United Kingdom, and the United States ("AUKUS") and the Comprehensive and Progressive Agreement for Trans-Pacific Partnership ("CPTPP"). These alliances represent an attempt to counterbalance China's increasing influence in global supply chains and underscore the increasing importance of shared strategic interests in the evolving world order. Despite protests from China, these alliances present an opportunity for geopolitical diversification and cooperation rather than escalation.

AUKUS, an agreement focused on technology exchange and defence cooperation between Australia, the United Kingdom, and the United States, is symbolic of a significant strategic pivot in the Indo-Pacific region. This alliance aims to counterbalance China's regional influence and presents opportunities for collaboration and technological innovation. These nations can cultivate independent and resilient supply chains through shared expertise and resources, fostering a collective defence against potential vulnerabilities.
Similarly, the CPTPP, a multilateral free trade agreement, presents an alternative to China's trading dominance. Advocating economic resilience among member nations provides a platform for diversified manufacturing and a shift away from an overly Asia-centric production model. These efforts towards diversification not only insulate the participating nations from potential disruptions but also stimulate innovation and competition, which are vital drivers for economic growth.

Future Prospects

The dependence of democratic industrial nations on China's monopoly in the rare earths industry cannot be overstated. Despite early steps toward onshoring and diversifying global supply chains and pursuing technological innovation to offset supply chain disruptions, the scale of this dependence is not easily or rapidly reducible. It will likely endure for another decade, necessitating strategic and coordinated responses to build viable alternatives.

The efficacy of recent initiatives to address global supply chain vulnerabilities remains uncertain. Still, democratic nations seem to be moving in the right direction by endorsing onshoring, strategic investments, and stockpiling as risk mitigation strategies. Tesla's recent move to exclude rare earths in its next-generation electric vehicles provides an example of the industrial innovation that could lessen the strategic challenges discussed in this report.[103]

The liberal world order is transforming, partially prompted by China's remarkable rise. Initially formed to maintain peace and stimulate international cooperation, international institutions are now confronting challenges to their relevance and legitimacy. Non-democratic states are increasingly shaping their agendas and global governance norms. The emergence of arrangements like AUKUS suggests future alignments and common policy approaches among the Anglosphere nations. These developments and the maturing geopolitical, economic, and security interests embedded in new international alliances will shape the broader context in which discussions of global supply chains, industrialisation, net zero goals, and geopolitical competition occur. As the investment landscape evolves, Western democracies must further focus on building their resilient supply chains to navigate potential future geopolitical crises. Furthermore, at least in strategically vital areas, the gradual "de-risking" from China is likely to persist.

While the journey towards reducing dependence on China's rare earths industry will be long, the stakes are high. Addressing global commodity and energy supply chain vulnerabilities requires comprehensive strategies integrating technological innovation, strategic alliances, industrial policy, and environmental responsibility. By acknowledging and confronting these risks, Western economies can bolster their energy security and contribute to global stability and the robustness of the liberal international order. The vagaries of geopolitical tension will act as the catalyst, and it is wise to lessen vulnerabilities. The West must diversify its resource dependencies for the green transition before decommissioning its legacy infrastructure.

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