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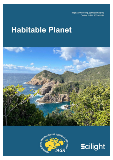

Article

Critical Metals: The Driving Force Behind Evolving Geopolitical Strategies in an Energy-Hungry World

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ABSTRACT

Critical metals are integral to mineral deposits that formed periodically over thousands to millions of years and are thus non-renewable resources. They are extremely rare with mines representing much less than 1% of the Earth's land surface. Due to an almost 10 times increase in world population since the Industrial Revolution, economic geologists have identified that there are finite resources of critical metals that can be mined economically with these facing exhaustion in an increasingly technological civilization. This threat is exacerbated by Net Zero policies which have increased use of critical metals for clean energy technologies. At present, demand is exceeding supply for some critical metals, rapidly leading to global geopolitical tensions that are further aggravated by the heterogeneous global distribution of metal deposits mineable under current economic, social, and environmental constraints. Western countries, the most committed to reach Net Zero by 2050, lack the stable supply chains for critical metals to manufacture solar panels, wind turbines, and electrical vehicles and are losing the energy security to manufacture them. The increasing demand over supply has led to unprecedented rises in the prices of Cu, Ag, Au, and other metals. Survival of modern industrialized civilization requires conservation of critical metals via commercial recycling. Increased metal prices may allow lower grade ores from greater depths to be mined from existing mining leases, but these will require increased energy to exploit metals with increased waste an additional environmental issue.

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Research Highlights

- Currently demand exceeds supply for some critical metals, rapidly leading to global geopolitical tensions.
- Survival of modern industrialized civilization requires conservation of critical metals via commercial recycling.
- Increased energy to exploit metals with increased waste poses additional environmental issue.
- Humanity is at a critical energy crossroads which needs rapid resolution.

1. Introduction: Nexus between Metals and Conflicts

There has been growing global demand for critical metal resources due to the world's continued population growth and the proclaimed green energy transition with the objective to replace fossil fuels by mainly wind and solar energy while retaining or increasing hydrogen and geothermal energy [1–6] as summarised in [7]. Additionally, critical metals are essential commodities for the military and defence industry in the manufacture of high-tech equipment and weapons. Rare critical metals such as U and W are also essential components for armour-penetrating kinetic energy ammunition, whereas rare-earth elements (REE) and critical trace metals such as In and Cd are key materials in the manufacture of electronic and GPS equipment, stealth technology, and radar absorbent coatings for military applications [8–13]. Precious metals such as Au and Ag are not only required in the electronic and aeronautical industries, but are also in increasing demand in International Finance as strategic hedges to offset devaluing of currencies due to inflation, economic crisis, and/or geopolitical tensions [7].

However, critical metal resources are limited in availability due to their heterogeneous distribution between different countries and competing political blocks such as BRICS and the USA protection alliances [5, 14–16]. More specifically, the global geological reserves of critical metals including Cr (80 vol%), Pd and Pt (both 64 vol%) are restricted to South Africa, over 65 vol% of global geological Co reserves are restricted to the Democratic Republic of Congo, and the largest global geological reserves of Cd (42 vol%), In (73 vol%), REE (70 vol%), and W (58 vol%) are located in China [13]. The inhomogeneous distribution of global metallic mineral resources [15, 17–19] has important strategic and geopolitical implications.

The supply chains for critical metals are threatened by their natural scarcity, their heterogeneous geographical distribution, and their current lack of substitution or recycling at acceptable cost. In 2026, commercial recycling and related organizational activities are still in their infancy [4, 20, 21] and the mining and exploration industries are severely restricted by increases in environmental and human rights issues, and sovereign risks [7, 14, 22]. The UNEP report on recycling rates indicates that the recovery rate in the EU of critical metals such as Li from existing Li-ion batteries is still $<5\%$ [23, 24]. Importantly, if a sustainable circular economy is to be developed both recycling at industrial scale and global mineral exploration are essential in order to secure a sufficient supply of critical metal resources for an increasingly energy-hungry society [6, 13, 15]. At current consumption rates, the dilemma of lack of the above essential factors raises severe geopolitical issues and potential supply risks for several critical metals at least in the mid- term and beyond [5, 14, 16, 25–27].

2. Rise to Criticality of Critical Metals and Geopolitical Development

As an example of the historical strategic importance of metals, the Swedish Baltic Empire was built largely on its superior trade networks and metallurgical processes in steel production [28], manufactured from iron mined from the giant Kiruna-type magnetite ores [29]. The German invasion of Denmark and Norway during World War II was intended to isolate these strategic iron ores of neutral Sweden from the western allies [30]. Previously, even after World War I, iron and coal continued to play a geopolitical role with Alsace Lorraine on the Franco-German border ceded alternately to France and Germany three times before World War II [15]. After the end of World War II, humanity divided into two major geopolitical blocks, NATO and Warsaw Pact, with increasing geopolitical tensions and strategic rivalries among them also known as the 'Cold War'. During this period, on 19 December 1973, U.S. Senator Walter Mondale called for the creation of a National Shortages Board to identify and cope with potential shortages of essential critical materials [31, 32] in order to ensure secure supply chains for the U.S. industry and also in response to the U.S. Senate approving the disposal of substantial quantities of Al, Cu, Zn, and Mo from the countries strategic national stockpiles just one day before. However, the geopolitical situation dramatically changed again with the fall of the Berlin Wall in October 1989, resulting in the sudden end of the Warsaw Pact. This event initially led to a period of geopolitical relaxation and almost a feeling of near invincibility of the people in many western countries, with some contemporary academics prematurely proclaiming the "end of history" [33]. However, history went on and most recently the world began to split again into competing political blocks such as the USA protection alliances (Figure 1a) and BRICS (Figure 1b). Additionally, the continued rise of world population as well as technological developments, including the advent of high-tech devices such as computers, laptops, and smartphones met with the gradual depletion of mineable high-grade mineral resources [7, 34]. In combination, these processes triggered an increasing global competition for free access to metallic mineral resources by major power groups including BRICS, EU, and USA [7, 15].

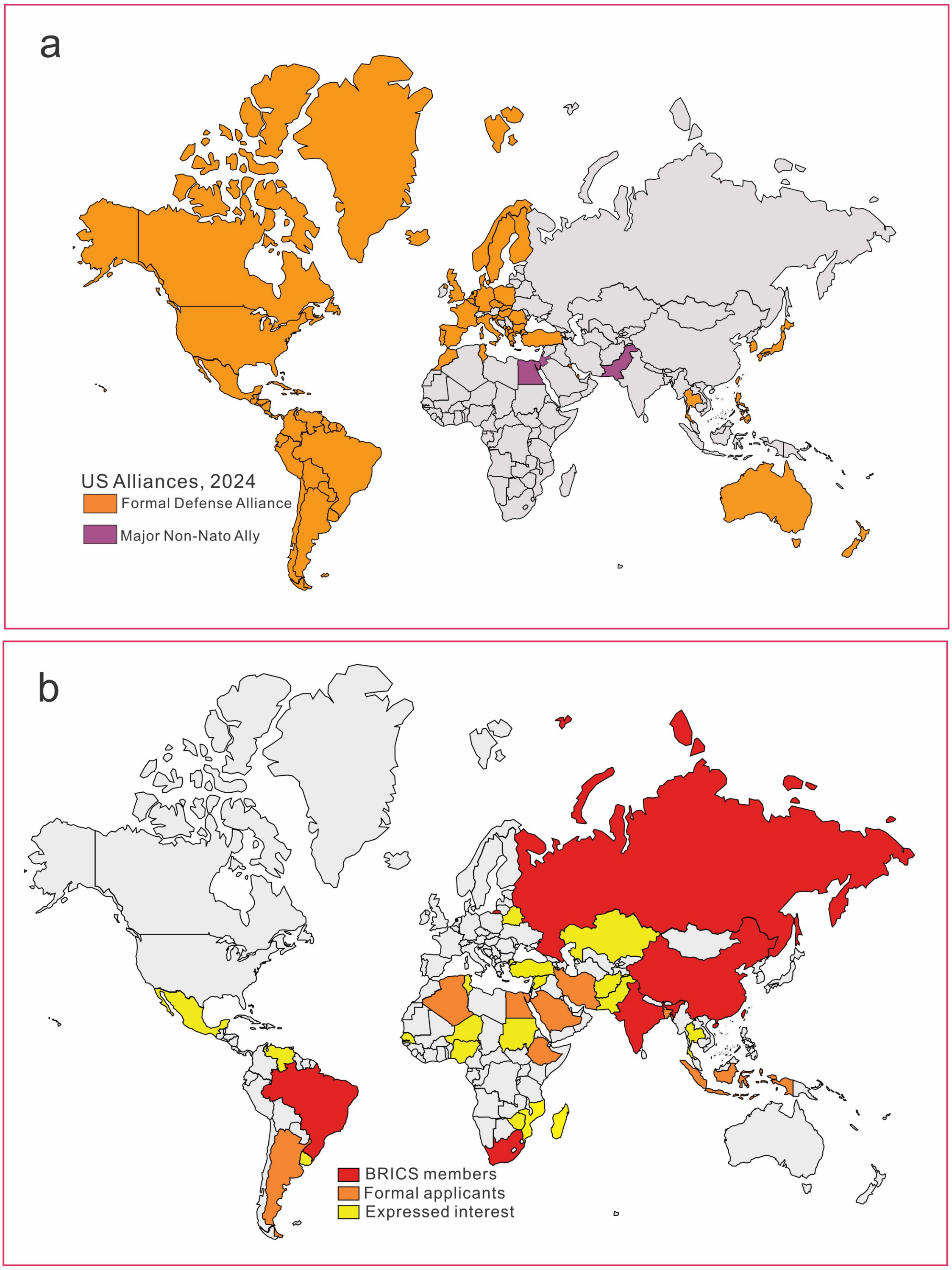


Figure 1. (**a**) Geographical overview of the USA Protection Alliances; (**b**) Geographical overview of the BRICS States.

Additionally, rising geopolitical concerns on the potentially ‘catastrophic’ effects of climate change have led to the so-called ‘green energy’ transition [35, 36] and the development of ’Net Zero’ policies proclaimed by the United Nations Framework Convention on Climate Change. The policy of reducing greenhouse gas emissions to Net Zero by 2050 was accepted and adopted by 196 Parties in the landmark Paris Agreement during the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. The adoption of green energy by global societies aims to reduce their dependence on fossil-fuel energy resources through use of cleaner industrial production technologies [37] and manufacture of wind turbines, solar panels, and electric vehicles [6, 7, 38]. Importantly, the latter causes a dilemma as the production of clean energy devices consumes large quantities of critical metal resources as illustrated in Figure 2 [7, 15]. At the same time, recent studies point out the challenge of an increasing electric power demand to fuel modern supercomputer centres for A.I. applications [39–41].

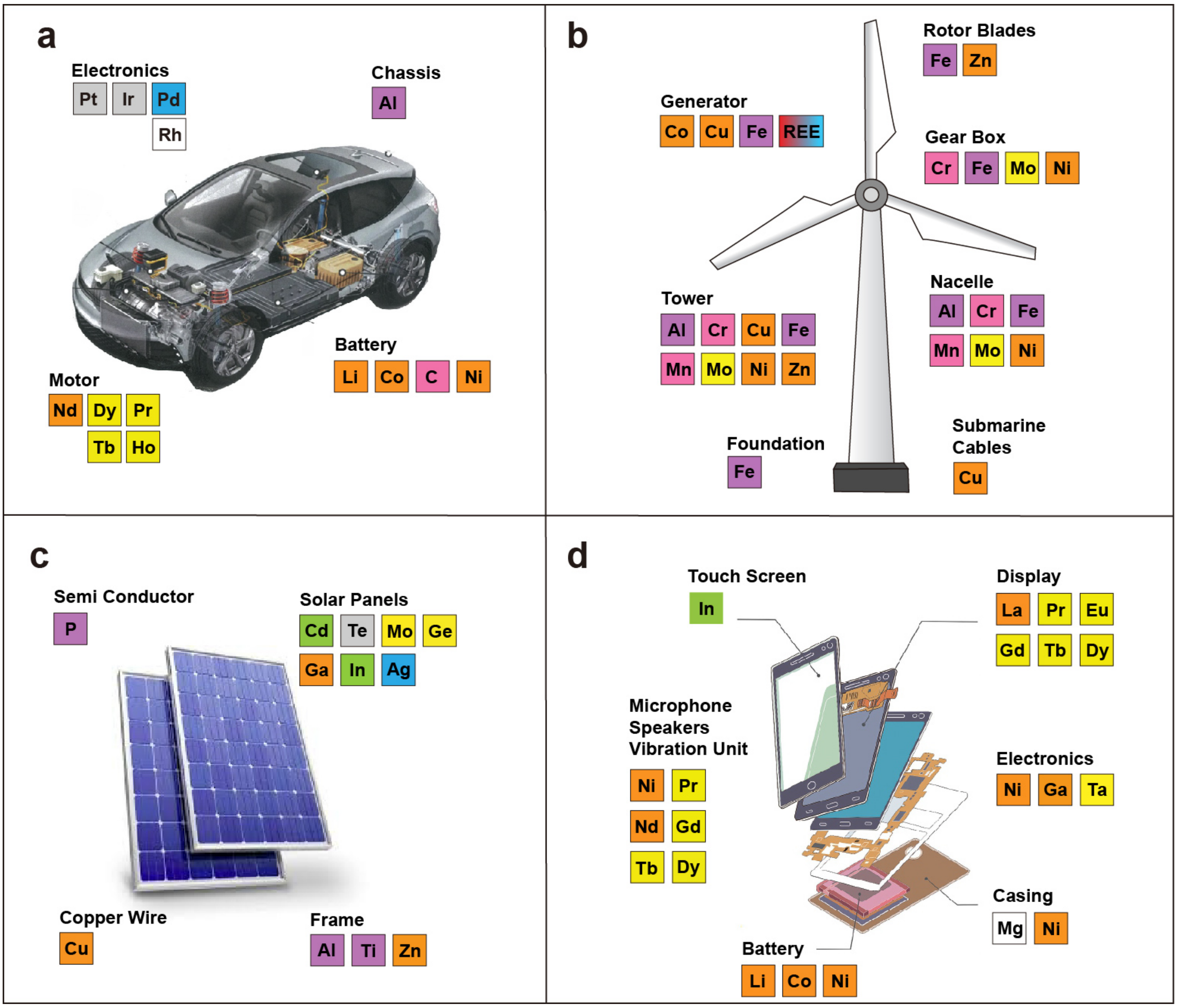


Figure 2. The use of critical metals for the manufacture of: (**a**) Electrical vehicles; (**b**) Wind turbines; (**c**) Solar panels; and (**d**) Smartphones. (**a**) modified from [42]; (**b**) from [43]; (**c**) from https://x.com/theminingstory/status/1385238107583361028; and (**d**) from [44] and [45]. Critical metals are shown in different colours depending on their average crustal abundance, see also [7]: *abundant metals* with >100 ppm (purple), *scarce metals* with 10–100 ppm (orange), *rare metals* with 1–10 ppm (yellow), *trace metals* with <1 ppm (light green and grey), and *precious metals* (blue), respectively.

More recently, the terms 'critical minerals' and 'critical metals' have become increasingly used for those metallic mineral resources which are involved in the manufacture of the so-called 'clean energy' instruments (Figure 2), although, in contradiction of intent, most wind turbines and solar panels have been constructed using conventional energy provided from coal, hydrocarbons, and nuclear reactors [5, 7, 38]. Frank et al. [46] define 'critical minerals' as those that are vulnerable to disruption, especially during periods of global geopolitical tensions. The 'criticality' of those metallic mineral resources is defined by their global scarcity, the potential for disruption of their supply chains, and the ability to exploit them commercially within dictated environmentally responsible constraints [38].

3. Systematic Inventory of Critical Metals

The geopolitical role of resources of critical metals is based on their use as critical commodities for industry and military, their natural scarcity, and their heterogeneous distribution between different countries. A systematic inventory of critical metals is provided by Tables 1–5, in which the nature of ore mineral, major hosting types of mineral deposits, main global producers, and main industrial uses are given for abundant, scarce, rare, precious, and trace critical elements. Supply risks are qualitative due to uncertainties relating to geopolitical issues discussed below. Figure 3 complements these Tables by illustrating the location of the most significant metallic mineral systems worldwide. Note that the highly industrialized EU and Scandinavian countries lack the required stable supply chains to provide them with critical metal resources. In contrast, the majority of the global geological metal reserves such as Cr (80 vol% South Africa), Co (65 vol% Democratic Republic of Congo), Mo (40 vol% China), PGEs (>60 vol% South Africa), REEs (70 vol% China), and W (58 vol% China) are concentrated in three countries resulting in strategic geopolitical imbalances (Figure 3). More specifically, the increasing demand for, and the heterogeneous distribution of, critical metal resources have the potential to lead to supply risks, trade wars, or even severe physical depletion in the near future. Hence, the rise of two major competing political and economic blocs such as the BRICS states (Brazil, Russia, India, China, South Africa) and the USA protection alliances countries, that importantly include Australia, Canada, Chile, Japan, Peru, and South Korea, is of geopolitical concern. Additionally, the increasing demand for critical metals due to Net Zero policies and the green energy transition further raise the severity of these geopolitical issues [7].

Table 1. Ore minerals, Deposit types, Main producers, Supply risk, and Main industrial uses of abundant critical metals. Deposit types are shown in broad order of current importance based on incomplete data. Relative importance may vary significantly with historical major deposit types being supplanted by others with advent of improved mining technologies.

Metal	Ore Minerals	Deposit Type	Major Producers	Supply Risk	Main Industrial Use
Al	Gibbsite	Bauxite	China (BRICS) sourced from Guinea and Australia	Moderate	Construction, Aeronautics
Ti	Ilmenite	Layered intrusion, Beach sands	China (BRICS), Mozambique, South Africa (BRICS)	Moderate	Steel, Alloys, Pigment
V	V-rich magnetite	Layered intrusion	China, Russia, South Africa (BRICS)	Moderate	Steel, Alloys
Cr	Chromite	Layered intrusion, Podiform	South Africa (BRICS)	Very high	Steel, Alloys
Mn	Braunite, Kutnahorite	Mn-rich BIF	South Africa (BRICS)	Moderate	Steel. Alloys
Fe	Hematite, Magnetite	BIF	Australia (US Alliance), Brazil (BRICS)	Low	Steel, Construction
Zr	Zircon	Beach sands	Australia (US Alliance), South Africa (BRICS)	Low	Computer, Television
Ba	Barite	Hydrothermal veins	India, China (BRICS)	Low	Semiconductors, Drilling muds
C	Graphite	Graphite schists	China (BRICS), Madagascar	High	Lubricant, Electrodes, Graphene

Table 2. Ore minerals, Deposit types, Main producers, Supply risk, and Main industrial uses of scarce critical metals. Deposit types are shown in broad order of current importance based on incomplete data. Relative importance may vary significantly with historical major deposit types being supplanted by others with advent of improved mining technologies.

Metal	Ore Minerals	Deposit Type	Major Producers	Supply Risk	Main Industrial Use
Ni	Pentlandite, Garnierite	Mafic intrusion, Laterite	Indonesia, Philippines (US Alliance)	Moderate	Fertilizer, Batteries, Anti-corrosion
Cu	Chalcopyrite, Bornite	Porphyry-, Zambian-type, IOCG	Chile, DRC, Peru	Moderate	Automobiles, Electronics, Green energy
Zn	Sphalerite	SEDEX, MVT, BHT	China (BRICS), Australia (US Alliance), Peru	Low	Batteries, Galvanization
Pb	Galena	SEDEX, MVT, BHT	China (BRICS), Australia (US Alliance), USA	Low	Batteries, Plastic, Green (solar) energy
Co	Columbite, Tantalite	Pegmatite, Carbonatite	Brazil (BRICS), DRC	Very high	Batteries, Magnets, Alloys
Li	Spodumene	Pegmatite, Brine	Australia (US Alliance), Chile, China (BRICS)	High	Batteries, E-vehicles, Alloys
Ga	Diaspore, Boehmite	Byproduct from Bauxite	China (BRICS)	Very high	Semiconductors, E-vehicles, Green (hydrogen) energy

Table 3. Ore minerals, Deposit types, Main producers, Supply risk, and Main industrial uses of rare critical metals. Deposit types are shown in broad order of current importance based on incomplete data. Relative importance may vary significantly with historical major deposit types being supplanted by others with advent of improved mining technologies.

Metal	Ore Minerals	Deposit Type	Major Producers	Supply Risk	Main Industrial Use
Mo	Molybdenite	Porphyry-type	China (BRICS), Chile (US Alliance)	Moderate	Steel, Alloys, Lubricant, Fertilizer
Sn	Cassiterite	Greisen	China (BRICS), Indonesia	Moderate	Solder, Batteries, Magnets, Green (solar) energy
Cs	Pollucite	Pegmatite	Canada, Australia (US Alliance)	High	Optics, Green (solar) energy, Drilling fluids
W	Wolframite	Skarn, Quartz vein	China, Russia (BRICS)	High	Steel, Alloys, Armor plates, Magnets, Green (wind) energy
PGEs	Cooperite, Sperrylite	Layered intrusion	South Africa, Russia (BRICS)	Very high	Car exhaust catalysts, Liquid crystal display
Sb	Stibnite	Veins, Carbonate replacement	China, Russia (BRICS)	High	Green (wind) energy, Steel, Alloys, Bearings
Th	Monazite, Bastnäsite	Beach sands, Carbonatite, Veins	India, Brazil (BRICS)	Moderate	Nuclear power, Ceramics, Medicine, Alloys
U	Uraninite, Pitchblende	Roll-front, Unconformity types	Kasakhstan, Canada (US Alliance)	Moderate	Nuclear power, Medicine, Chemical industry
REEs	Monazite, Bastnäsite	Carbonatite, Ionic clays, Beach sands	China (BRICS)	High	Batteries, Magnets, Green energy, LED lights

Table 4. Ore minerals, Deposit types, Main producers, Supply risk, and Main industrial uses of precious critical metals. Deposit types are shown in broad order of current importance based on incomplete data. Gold data from multielement deposits are only accessible in individual mining company reports. Relative importance may vary significantly with historical major deposit types being supplanted by others with advent of improved mining technologies.

Metal	Ore Minerals	Deposit Types	Major Producers	Supply Risk	Main Industrial Use
Au	Native gold, Electrum, Gold-rich Pyrite or Arsenopyrite, Acanthite, Calaverite, Sylvanite.	Orogenic, Porphyry-Epithermal, Placers, Carlin-type, IOCG, Witwatersrand	China (BRICS), Australia (US Alliance)	Moderate	Finance, Jewelry, Aeronautics, Electronics, Medicine
Ag	Argentite, Polybasite, Proustite, Native silver, Silver-rich Galena	Epithermal, Silver-rich Pb–Zn veins	Mexico (US Alliance), China (BRICS)	Moderate	Finance, Jewelry, Electronics, Batteries, Medicine, Green (solar) energy

Table 5. Ore minerals, Deposit types, Main producers, Supply risk, and Main industrial uses of trace critical metals. Deposit types are shown in broad order of current importance based on incomplete data. Relative importance may vary significantly with historical major deposit types being supplanted by others with advent of improved mining technologies.

Metal	Ore Minerals	Deposit Type	Major Producers	Supply Risk	Main Industrial Use
Se	Trace element in chalcopyrite	Byproduct in Porphyry and VMS systems	China (BRICS)	Very high	Batteries, Glass industry, Green (solar) energy
Cd	Trace element in sphalerite	Byproduct in SEDEX and MVT systems	China (BRICS)	Very high	Semiconductors, Alloys, Batteries, Transistors
In	Trace element in sphalerite	Byproduct in SEDEX and MVT systems	China (BRICS)	Very high	Semiconductors, Green (solar) energy
Te	Au, Ag, and base-metal tellurides	Porphyry and Epithermal systems	China (BRICS), Japan (US Alliance)	Very high	Semiconductors, Green (solar) energy

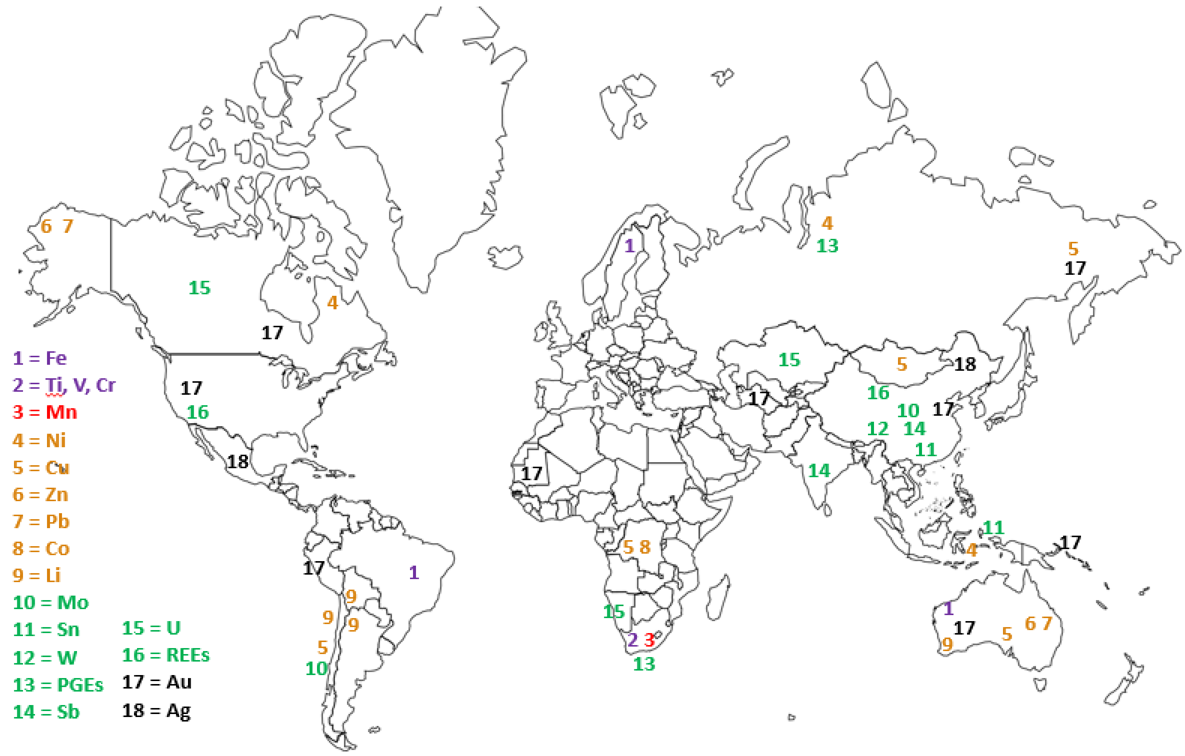


Figure 3. World map showing the most significant mineral districts globally. The numbers 1 to 18 refer to the different mineral systems. Different colors refer to abundant (purple), less abundant (red), scarce (orange), rare (green) and precious metals (black), based on their relative crustal abundance (see: [7]), respectively. 1 = Fe including Carajas and Minas Gerais (Brazil), Pilbara (Australia), and Kiruna (Sweden); 2 = Ti, V, Cr at Bushveld, South Africa; 3 = Mn in the Kalahari region (South Africa); 4 = Ni including Sulawesi (Indonesia, Voisey's Bay (Canada), and Norilsk (Russia); 5 = Cu including the Atacama region (Chile); Katanga (DRC), Olympic Dam (Australia), Oyu Tolgoi (Mongolia), and Peschanka (Russia); 6 = Zn including Red Dog (Alaska) and Broken Hill (Australia); 7 = Pb including Red Dog (Alaska) and Broken Hill (Australia); 8 = Co at Katanga (DRC); 9 = Li including the giant 'lithium triangle' (Argentina, Bolivia, Chile) as well as Greenbushes pegmatite (Australia); 10 = Mo including the Atacama region (Chile) and the North China Craton (China); 11 = Sn including greisen systems at Gejiu (China); tin placers in SW-Pacific (Indonesia); 12 = 4 W including northern Lhasa terrane and Zhuxi (both China); 13 = PGEs including Bushveld (South Africa) and Norilsk (Russia); 14 = Sb Xikhuangshan district (China); 15 = U including Chu-Sarysu Basin (Kazhkstan) and Athabasca Basin (Canada); 16 = REEs including carbonatites Bayan Obo (China) and Mountain Pass (USA), and heavy REE ionic clays (China); 17 = Au including: giant orogenic gold systems in Muruntau (Uzbekisthan), Jiadong (China), Superior Province (Canada), Yilgarn Craton (Australia), and Birimian sequences (West Africa); Carlin-type systems (Nevada, USA), epithermal systems at Yanacocha (Peru) and Lihir (Papua New Guinea); porphyry Au in Peschanka-Nakodhka cluster (Siberia, Russia); 18 = Ag including Zaratecas (Mexico) and Xingmeng province (China).

4. Impact of Critical Metals Approaching Severe Depletion/Exhaustion

Mainstream media barely ever question the concept that climate change is induced by human activity in releasing greenhouse gasses into the atmosphere that cause global warming and extreme climatic events. However, Groves et al. [47] demonstrate that climate change with cyclic variations in global temperatures due to background factors such as solar activity, orbital forcing, ocean circulation, and greenhouse gases has occurred over geological, anthropological, and human timescales with rapid catastrophic changes essentially mainly related to sudden large volcanic events. Given this natural variation, it is uncertain how much human activity is actually impacting the climate, although massive increases in human population and their migration into geographically vulnerable areas means that extreme climatic events have greater impact on them. Mainstream media also rarely question the related concept that human-impacted climate change is threatening the life chances of millions of animal and plant species around the world. However, a recent scientific report from the United Kingdom Royal Society reveals that species-level extinctions related to climate change "have not significantly increased over the last approximately 200 years" [48, 49]. Additionally, it documents that decadal extinction rates over the last 100 years had "significantly declined" for arthropods and plants, the two groups of organisms encompassing most known global biodiversity. Overall, the report reveals that extinction rates have increased over the last 500 years, "but generally declined in the last 100 years" [48, 49].

Although largely ignored by politicians and the media, there have been increasing warnings from researchers that resources of critical metals in currently mined deposit types and at current ore grades are rapidly declining. Some researchers believe that some specific critical metals may even be exhausted by 2050, which is simply the end of only the first of an infinite series of rounds of Net Zero climate remediations to achieve long-term Net Zero [14, 25, 50]. Based on current indicators, it is unlikely that these 'clean energy' resources can be rapidly replaced through mineral exploration as the host deposits are at increasingly deeper crustal levels and normally concealed by thick regolith and young sedimentary cover sequences [7, 51, 52]. Hence, future greenfield exploration has to overcome severe challenges, and any new discoveries will be more expensive to mine [52]. More specifically, future exploration success is challenged by the risk-averse nature of most mining companies, strict environmental and indigenous population issues, as well as a negative public perception of mining and hydrocarbon extraction in most western societies [7, 53, 54] despite our civilization being largely based on the products of such activities. Additionally, the economic recovery of the majority of critical metals from recycling is still in its infancy, at least at industrial scale, with the exception of aluminium and the precious metals [4, 6, 13, 21].

The future challenges to secure stable supply chains for metallic mineral resources are already reflected by sharply rising metal prices at COMEX and the London Metal Exchange (Figure 4). The price of Cu rose almost 38% during 2025 and soared to new records above US$13,000 a metric ton in early-2026 [55]. During the same period, Ag rose from a steady state of <US$10 to approximately US$100 in early 2026 with further rises likely as China has decided to restrict its Ag exports [56, 57] although the price has temporarily fallen to US80$ per oz in the month since Figure 4 was drafted. However, it should be noted that precious metals such as Au and Ag do not only represent essential commodities in the global electronics and aviation industries, but they are also increasingly used in International Finance by Federal Reserve Banks and private Hedge Funds to hedge their portfolios against the risks of inflation or geopolitical tensions, as previously discussed by Müller et al. [7]. More specifically, recent studies document a significant relationship between geopolitical risk and bubbles in gold [58] and silver [59–61] prices.

As briefly outlined above, based on current trends, the mineral exploration and mining industry is hard pressed to deliver new conventional mineral discoveries for short-term mine development, particularly enhanced because of extended delays between discovery and exploitation [52]. Thus, lower grade deposits must be exploited with even further rises in metal prices with growing demand causing further increases in energy both for the mining and metallurgical treatment of metallic ores [62, 63].

Figure 4. Schematic chart illustrating the price variations of copper (blue), gold (orange), and silver (green) between 2021 to early 2026. Copper price in US$ per pound and Au and Ag prices in US$ per ounce. Data are taken from [64] so are valid for the first week in February 2026.

5. Rise in Geopolitical Tensions

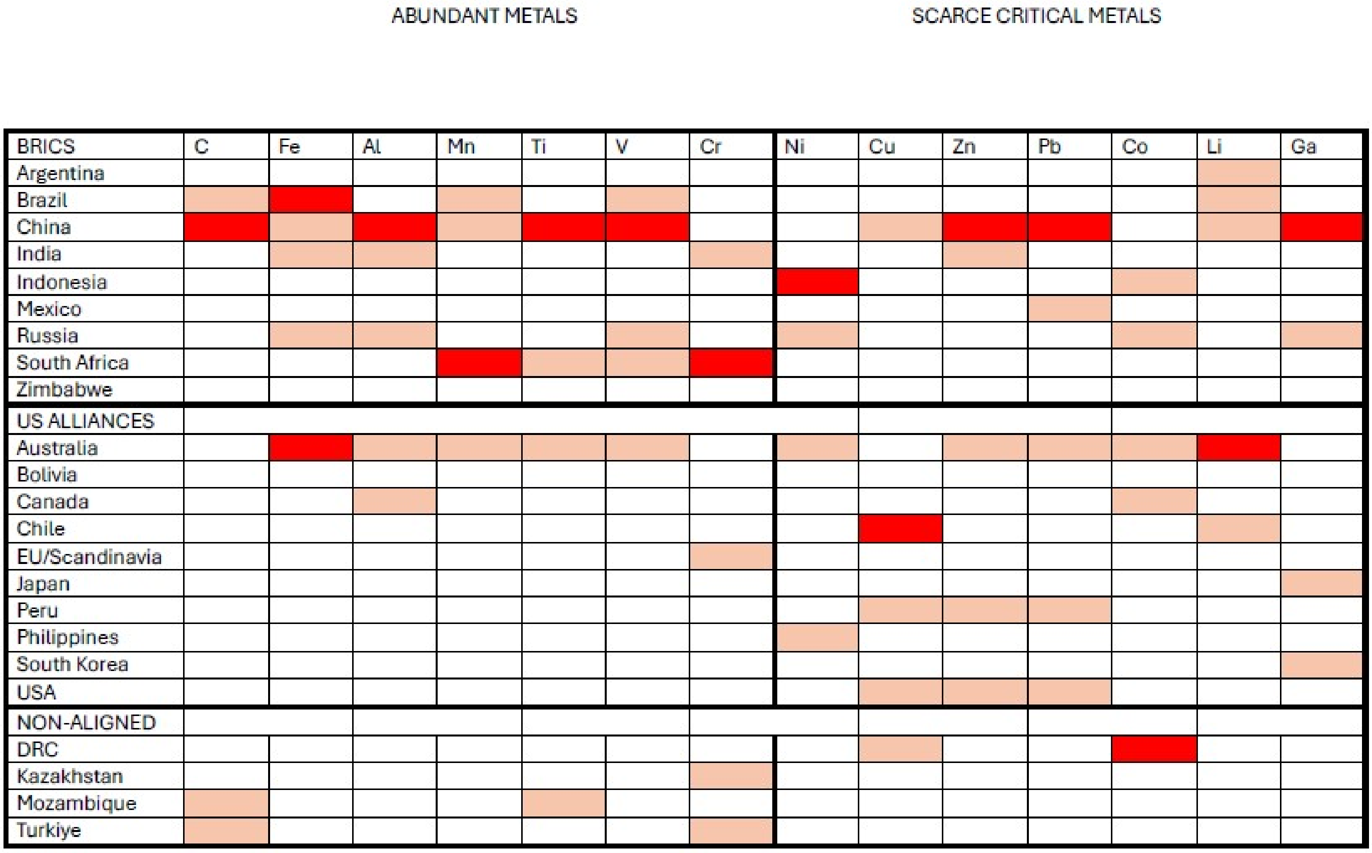
The global rise in geopolitical tensions with emphasis on the access to metallic mineral resources is not only reflected by the Russian ‘Special Operation’ in the mineral-rich Donbas region of Ukraine [65] (Figure 5), but also by the signing of an energy and critical minerals agreement between the U.S. and Ukraine. This new agreement will allow the U.S. to share in future revenue earned from Ukraine’s critical mineral reserves [66].

Another recent example of rising geopolitical tensions is reflected by the border dispute between the Democratic Republic of Congo (DRC) and Rwanda [67]. The DRC controls the largest Co reserves on Earth, with both the DRC and Rwanda highly endowed with Co-Ta (so-called ‘coltan’) resources along their border. However, relations between these the DRC and Rwanda had long been strained by conflict between armed groups along the eastern border of the DRC, where there are long-lived political tensions [67]. This long-lasting political instability in the DRC had even caused the temporary closure of mines elsewhere in the country and resulted in supply delays severely affecting battery production for E-vehicles, among other issues [15]. However, under the guidance of the Trump Administration, an uneasy peace deal has eventually been struck between both countries [67, 68]. In this context, it is also interesting to note that EU countries such as Germany are still generously donating development aid to the DRC, whereas China is executing an increasingly strategic plan involving the building of critical infrastructure projects including ports, roads, rail, and power generation [15]. Cobalt is critical for numerous ‘clean energy’ enterprises and geopolitical tensions are bound to increase due to the dominance of the DRC in global Co resources.

Nickel, another critical metal with widespread use in the clean energy transition, illustrates the geopolitical forces at play for metals whose demand may soon exceed demand [69]. Nickel has traditionally been produced in smelters fed from Ni–Cu sulfide ores accessed from more labour-intensive underground mines in Canada, Russia, and Australia in particular. Meanwhile, there has been lesser production from rare metallurgically and environmentally friendly supergene deposits, such as those in New Caledonia, which are generally lumped under the term lateritic Ni deposits. However, Chinese mining companies have recently constructed lower cost high pressure acid leach treatment plants for lateritic Ni ore in Indonesia in order to replace high-cost Ni from Ni-sulfide deposits in terms of battery-grade Ni [7, 70]. A major environmental issue is that tailings from these leach plants have a severe negative impact in the humid Indonesian environment in which mining and processing occurs [71]. This would never be approved by western governments with their strict environmental legislation. The release of this Indonesian Ni has caused a massive retreat in nickel prices with the result that Australian and Canadian mining companies that exploit their Ni from Ni–Cu sulfide ores being forced to ‘mothball’ their mining operations [72]. This has significant geopolitical consequences while pushing major well established Ni producers from Ni–Cu sulfide deposits out of production [27, 73] and completely changing the dynamics of the global Ni market. As a result, 50% of global Ni now comes from Indonesia with significant production from the Philippines and New Caledonia [74, 75].

Figure 5. Simplified map of eastern Ukraine showing broad distribution of major mineral resources including the Krivoy Rog Fe and Nikopol Mn deposits. Modified from [17, 45, 76].

The USA currently under the Trump Administration appears to recognize the strategic imbalance between BRICS and USA protection alliances metal resources (Figures 6 and 7) with China having world dominance in many critical metals and using it, for example, in retaliation for export bans on computer chips [58, 77]. Recent examples are the Chinese restrictions on the export of critical metals such as Ge, Ag, REE, and W [56, 78], thus further escalating metal prices. The US government sets out to redress this geostrategic imbalance by the re-activation of the 'Monroe doctrine' and with tariff-related deals for critical metals with Ukraine, Australia and other countries [79–81]. The 'Monroe doctrine' refers to US President James Monroe's 1823 annual message to Congress that requested European powers not to interfere in the affairs of countries within the region of the Western Hemisphere [82]. However, the recent kidnapping of the Venezuelan president and the seizing of oil assets in Venezuela, a country also rich in critical metals such as Au, REE, and U is widely regarded as a novel geopolitical strategy with some media even proclaiming a new brand of 'colonialism' [83] or 'imperialism' [84]. Recent attempts by the U.S. government to 'buy' Greenland for its geostrategic military importance and its rich critical metals endowment including undeveloped Li, Pb–Zn–Ag, and REE resources, as well as potential PGE deposits, may be also regarded as part of this novel geopolitical strategy [85, 86]. Importantly, Greenland has also huge potential for the exploitation of offshore oil and gas resources [85]. These recent developments may herald an upcoming period of increasing geopolitical competition between world superpowers to secure free access to the scarce and heterogeneously distributed mineral resources such as hydrocarbons and critical metals [58].

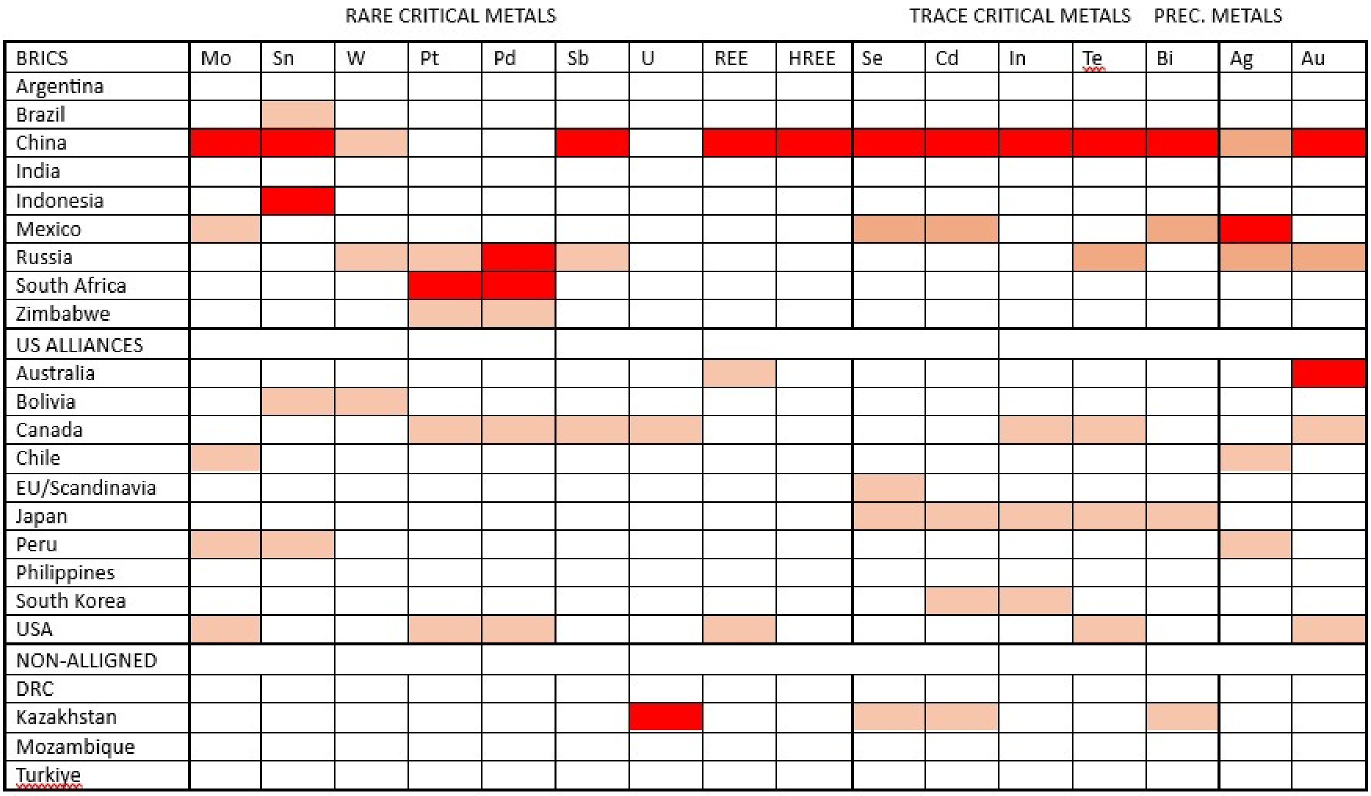


ABUNDANT METALS

SCARCE CRITICAL METALS

BRICS	C	Fe	Al	Mn	Ti	V	Cr	Ni	Cu	Zn	Pb	Co	Li	Ga
Argentina													🟧	
Brazil	🟧	🟥		🟧		🟧							🟧	
China	🟥	🟧	🟥	🟧	🟥	🟥			🟧	🟥	🟥		🟧	🟥
India		🟧	🟧				🟧			🟧				
Indonesia								🟥				🟧		
Mexico											🟧			
Russia		🟧	🟧			🟧		🟧				🟧		🟧
South Africa				🟥	🟧	🟧	🟥							
Zimbabwe														
US ALLIANCES														
Australia		🟥	🟧	🟧	🟧	🟧		🟧		🟧	🟧	🟧	🟥	
Bolivia														
Canada			🟧									🟧		
Chile									🟥				🟧	
EU/Scandinavia							🟧							
Japan														🟧
Peru									🟧	🟧	🟧			
Philippines								🟧						
South Korea														🟧
USA									🟧	🟧	🟧			
NON-ALIGNED														
DRC									🟧			🟥		
Kazakhstan							🟧							
Mozambique	🟧				🟧									
Turkiye	🟧						🟧							

Figure 6. Global distribution of top five countries in terms of production of abundant critical metals (>100 ppm crustal abundance), scarce critical metals (10–100 ppm crustal abundance). Metals are listed in terms of increasing atomic numbers. Boxes in red signify #1 or equal #1 producer. Boxes in orange signify the other top 5 producers. The data represent a consensus between normally consistent tables of metal production on websites moderated using USGS Mineral Commodity Summaries and Wikipedia. Adapted from [15].



	RARE CRITICAL METALS									TRACE CRITICAL METALS					PREC. METALS	
BRICS	Mo	Sn	W	Pt	Pd	Sb	U	REE	HREE	Se	Cd	In	Te	Bi	Ag	Au
Argentina																
Brazil		🟧														
China	🟥	🟥	🟧			🟥		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥
India																
Indonesia		🟥														
Mexico	🟧									🟧	🟧			🟧	🟥	
Russia			🟧	🟧	🟥	🟧							🟧		🟧	🟧
South Africa				🟥	🟥											
Zimbabwe				🟧	🟧											
US ALLIANCES																
Australia								🟧								🟥
Bolivia		🟧	🟧													
Canada				🟧	🟧	🟧	🟧					🟧	🟧			🟧
Chile	🟧														🟧	
EU/Scandinavia										🟧						
Japan										🟧	🟧	🟧	🟧	🟧		
Peru	🟧	🟧													🟧	
Philippines																
South Korea											🟧	🟧				
USA	🟧			🟧	🟧			🟧					🟧			🟧
NON-ALLIGNED																
DRC																
Kazakhstan							🟥			🟧	🟧			🟧		
Mozambique																
Turkiye																

Figure 7. Global distribution of top five countries in terms of production of rare critical metals (1–10 ppm crustal abundance), trace critical metals (0.01–1 ppm crustal abundance) and precious metals. Metals are listed in terms of increasing atomic numbers. Boxes in red signify #1 or equal #1 producer. Boxes in orange signify the other top 5 producers. The data represent a consensus between normally consistent tables of metal production on websites moderated using USGS Mineral Commodity Summaries and Wikipedia. Adapted from [15].

6. The Geopolitical Future

During recent years, the public has been regularly bombarded by media reports of 'unprecedented' catastrophic weather events', which history shows us have well-documented historical equivalents when human populations were considerably lower and hence less impacted by them [15, 87–90]. Additionally, in most mainstream media there has been a notable silencing of dissenting voices and an apparent refusal to engage with alternative views on climate change [91, 92]. A recent scientific study of more than 13,000 Americans tested the ten most cited climate-messaging strategies drawn from 157 previous papers with the objective to find the key paragraph, the 'killer framing', that would change public beliefs and nudge behaviour, but unfortunately could not identify it [93]. A significant concern is that recent media focus on extreme weather events and related catastrophism [90] has resulted in the formation of a new 'green' mass movement under the euphemistic label of 'climate activism' [94]. In April 2023, climate activists glued themselves to the road in mid-London blocking all traffic and preventing ambulances to attend to emergencies [95]. Under the narrative of protesting against pollution caused by air traffic, German climate activists glued themselves to the main runway after breaking into Munich airport in May 2024 and causing a serious air traffic safety threat for passengers and aircrews [96, 97]. In January 2026, for the second time in less than four months, fanatical climate activists sabotaged the power supply of the south-eastern suburbs of Berlin, Germany's capital city, through a deliberate arson attack on a cable bridge over the Teltow Canal [98, 99]. The fire severely damaged high-voltage cables connected to the nearby Lichterfelde heat and power station and caused about 45,000 households and 2200 businesses to completely lose heat and light for several days [98, 99]. The Major of Berlin had to declare an emergency that lasted for five days and caused the evacuation of numerous old age residences and hospitals due to subzero temperatures of −12°. Instead of a subject of rational debate, climate change has become a battleground of extremist views that limit public activity and threaten energy stability.

There is a rising scepticism in western societies towards the implementation of one overriding option to save long-term human civilisation. It is becoming increasingly recognized that global Net Zero is unattainable [91], at least in the short-term [15], because so-called 'renewable' energy is powered by non-renewable critical metals that are rapidly becoming depleted in a world of uncontrolled population growth and increasing geopolitical tensions [5, 16]. It is also imperative to develop a sensible balanced portfolio that includes a broad energy mix with CO_2-free nuclear power, as being proposed in China's strategic energy plan for 2060 [100]. The German government which had officially banned nuclear energy and closed their last remaining nuclear power plants in 2023, in a move to switch to green energy production to meet its Paris Agreement commitments, has recently admitted it as a serious strategic mistake that has come at a high cost to both the economy and energy security for a major industrial nation [101–104]. At a business conference in the city of Halle in January 2026, German Chancellor Friedrich Merz explained that Germany's energy transition was the "most expensive in the world" and was severely limiting the country's energy generation capacity [101, 102]. He added that his government, which had been in power since winning parliamentary elections in Germany the previous year, had to correct the situation it inherited from its predecessors by planning the construction of new nuclear power plants [101–103]. However, it is expected that it will take up to 20 years before these new reactors can produce electricity, thus seriously challenging Germany's aim to generate at least 80% of its electricity from green energy sources by 2030 and to be completely carbon-neutral by 2045 [101–103] without jeopardizing energy security and its global industrial ranking. Even more recently, in an interview with British newspaper *The Telegraph*, Joe Kaeser, the CEO of Siemens Energy, criticized German officials for sacrificing cheap and reliable energy by abruptly abandoning fossil fuels [105]. Kaeser pointed out that in terms of global emissions, Germany's share was currently less than 2% and thus much lower than other industrialized countries including Brazil and India and thus meeting their Net Zero commitment would make little difference to greenhouse gas emissions at the global scale [105].

The looming threat of potential exhaustion of critical metals, with demand exceeding supply leading to rapidly increasing metal prices, should promote the rapid development of more effective commercial recycling capacities at industrial scale in the efforts to develop a sustainable circular economy for critical metals [6, 16, 25, 26]. Additionally, there is a need for global mineral exploration to become more effective, an increasingly forlorn hope in a world of increasing internal conflicts and increasingly unrealistic governmental, environmental and social requirements which severely hinder discovery and mining [3, 20, 22, 106].

The path to a sustainable circular economy will take time, common sense, and careful considerations. Hence, current geopolitical issues will exist with superpowers battling for supremacy in gaining critical metal assets through trade deals, 'colonization', or military conflicts [58]. During this period, remote countries like Australia that are rich in critical metals may themselves become targets for 'colonialization' in the geopolitical battle of superpowers. From a geostrategic point of view, western Europe and the EU may become increasingly irrelevant as they have extremely limited critical metal resources outside of Ukraine, Poland, Sweden, and Finland [22, 107–109]. This may also explain why the Trump Administration is beginning to become increasingly dismissive of the EU and NATO [110–112]. There is a looming risk that if the EU countries, and possibly Australia, continue to uncritically observe the Paris Convention on climate change, they are likely to face severe social problems in the near future in terms of their energy security with related adverse consequences for their economies and political stability.

In summary, we are probably only witnessing the beginning of a new geopolitical era in a world already struggling with internal wars, excessive public debt, terrorists, climate 'activists', massive migration movements from regional conflicts, persecution, or famine, unpopular governments, and a powerless UN which is unwittingly adding to the list of global challenges due to its short-term solutions without resolution of any of its long-term critical problems. A potential worst scenario may be a repeat of the collapse of the Bronze Age when conditions were remarkably similar as today in terms of severe depletion of mineable Cu and Sn (the critical metals of the era) in an economy based on global trade where established civilizations were being 'invaded' by 'sea people', widely considered to be refugees fleeing from famine induced by climate shifts or an uncertain future due to societal issues in their own lands [113, 114]. Perhaps Albert Einstein's prediction that World War IV would be fought with sticks and stones will be prophetic unless there is global awareness of the problem of limited non-renewable metal resources in time to address it in a logical non-partisan global manner.

7. Conclusions

For human populations it is imperative to realize that all currently used energy sources, apart from hydropower and to a lesser extent thermal power, are non-renewable resources that have formed over geological timescales and are being depleted at human timescales. Concern over climate change, which itself is a long-term enduring, but cyclic process at geological, anthropological, and historical timescales, has resulted in Net Zero policies that in turn have caused increasing use of non-renewable critical metal resources to produce clean energy, widely referred to incorrectly as 'renewable' energy. The generation of wind turbines, solar panels, and electric vehicles uses unprecedented amounts of some of the rarest non-renewable elements on the planet.

An almost 10-fold increase in world population since the Industrial Revolution has already raised the issue of potential extreme depletion to exhaustion of the finite resources of non-renewable critical metal that can be mined economically in an increasingly technological civilization. This threat has been severely exacerbated by Net Zero policies which have necessitated the increasing use of critical metals for clean energy technologies. Currently, the fact that demand is exceeding supply for some critical metals is rapidly leading to global geopolitical tensions that are further aggravated by the heterogeneous global distribution of conventional metal deposits. Due to global tensions, competing BRICS and US protection alliances have emerged with the former, including China, having superior production of most strategic critical metals used in solar panels, wind turbines, and electric vehicles. Since the advent of the current US leadership, trade wars using tariffs as bargaining and intimidating tactics involving critical metals have increased. It has become evident that countries within the US alliances, particularly in the EU where Net Zero by 2050 is a compulsive aim, cannot match the superior critical metal resources of BRICS. They lack the required critical metals to manufacture solar panels and are losing the energy security to manufacture all clean energy devices. These geopolitical tensions are fuelling US rapid attempts to gain secure supplies of critical metals through trade deals with China and other countries. The increasing demand over supply, in part fuelled by these geopolitical tensions, is leading to unprecedented rises in the prices of Cu, Ag, Au, and potentially other metals.

On a more positive note, recent technological innovations such as the invention of novel sodium-ion batteries, the proposed, although not yet implemented, development of a circular economy using industrial-scale recycling of critical metals, and the application of A.I.-supported tools to increase the discovery rate of global mineral exploration can potentially mitigate the current challenges. Importantly, conservation of critical metals via currently unavailable commercial recycling at industrial scale is essential if modern industrialized civilization is to survive. Regional mineral exploration with long timeframes from discovery to mine development cannot replace current resources in the short term. Lower grade ores could be mined from existing mining leases, but these will require increased energy to exploit metals and result in increased waste. Continued attempts to control the implied threat of climate change are almost certain to create a much larger threat to human civilization. It is time to pause, debate the issues, and develop a circular energy economy based on a sensible mix of energy sources that can only involve critical metals if commercial recycling can be established at industrial scale.

Author Contributions

D.M.: Conceptualization, Visualization, Formal analysis, Writing—original draft. D.I.G.: Conceptualization, Visualization, Supervision, Formal analysis; Writing—original draft. M.S.: Data curation; Writing—review and editing. C.X.Y.: Data curation; Writing—review and editing.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. D.M., M.S. and C.X.Y. are Editorial Board members of this Journal and were not involved in the review processing or decision to accept this paper.

Use of AI and AI-assisted Technologies

No AI assisted tools were used during the preparation of this paper.

References

1. Groves, D.I.; Santosh, M.; Zhang, L. Net zero climate remediations and potential terminal depletion of global critical metal resources: A synoptic geological perspective. *Geosyst. Geoenviron.* **2023**, *2*, 100136. https://doi.org/10.1016/j.geogeo.2022.100136
2. Santosh, M.; Groves, D.I.; Yang, C.-X. Habitable planet to sustainable civilization: Global climate change with related clean energy transition reliant on declining critical metal resources. *Gondwana Res.* **2024**, *130*, 220–233. https://doi.org/10.1016/j.gr.2024.01.013
3. Balaram, V.; Santosh, M. Critical metal deposits in terrestrial and oceanic environments and the global energy transition. *Habitable Planet* **2025**, *1*, 86–107. https://doi.org/10.63335/j.hp.2025.0008
4. Erkmen, A.N.; Ulber, R.; Jüstel, T.; Altendorfner, M. Towards sustainable recycling of critical metals from e-waste: Bioleaching and phytomining. *Resour. Conserv. Recycl.* **2025**, *215*, 108057. https://doi.org/10.1016/j.resconrec.2024.108057
5. Laurent, B.; Louvet, G.; Solé-Pomies, R.; et al. What makes minerals critical? Problematizing sovereignty in times of crisis. *Extr. Ind. Soc.* **2025**, *24*, 101720. https://doi.org/10.1016/j.exis.2025.101720
6. Liu, Z.; Wang, S.; Liu, B.; et al. Advanced oxidation processes for sustainable critical metals extraction and recovery: Mechanisms, applications, and future perspectives. *J. Environ. Chem. Eng.* **2025**, 120193. https://doi.org/10.1016/j.jece.2025.120193
7. Müller, D.; Groves, D.I.; Santosh, M. *Metallic Mineral Resources: The Critical Components for a Sustainable Earth*; Elsevier: Amsterdam, Netherlands, 2024, 474 pp.
8. Sharma, H.; Rawal, N.; Mathew, B. The characteristics, toxicity and effects of cadmium. *Int. J. Nanotechnol. Nanosci.* **2015**, *3*, 1–9.
9. Balaram, V. Rare earth elements: A review of applications, occurrence, exploration, analysis, recycling, and environmental

impact. *Geosci. Front.* **2019**, *10*, 1285–1303. https://doi.org/10.1016/j.gsf.2018.12.005

10. Dushyantha, N.; Batapola, N.; Ilankoon, I.; et al. The story of rare earth elements (REEs): Occurrences, global distribution, genesis, geology, mineralogy and global production. *Ore Geol. Rev.* **2020**, *122*, 103521. https://doi.org/10.1016/j.oregeorev.2020.103521
11. Huang, J.; Ding, Q.; Wang, Y.; et al. The evolution and influencing factors of international tungsten competition from the industrial chain perspective. *Resour. Policy* **2021**, *73*, 102185. https://doi.org/10.1016/j.resourpol.2021.102185
12. Kumar, A.A.; Sanislav, I.V.; Cathey, H.E.; et al. Geochemistry of indium in magmatic-hydrothermal tin and sulfide deposits of the herberton mineral field, Australia. *Miner. Depos.* **2023**, *58*, 1297–1316. https://doi.org/10.1007/s00126-023-01179-7
13. Müller, D.; Groves, D.I.; Zhang, L. Towards a circular economy: Modern recycling technologies for critical metals. *Gondwana Res.* **2025**, *152*, 12. https://doi.org/10.1016/j.gr.2025.05.009
14. Vivoda, V.; Matthews, R.; McGregor, N. A critical minerals perspective on the emergence of geopolitical trade blocs. *Resources Policy* **2024**, *89*, 104587. https://doi.org/10.1016/j.resourpol.2023.104587
15. Groves, D.I.; Müller, D.; Santosh, M.; et al. The heterogeneous distribution of critical metal mineral resources: An impending geopolitical issue. *Geosyst. Geoenviron.* **2025**, *4*, 100288. https://doi.org/10.1016/j.geogeo.2024.100288
16. Jung, S.; An, S.; Park, J.; et al. Assessment of a critical mineral recycling network: A case study on nickel recovery from production waste in Korean Eco-industrial Parks. *J. Ind. Ecol.* **2025**, *29*, 1197–1207. https://doi.org/10.1111/jiec.70026
17. Groves, D.I.; Vielreicher, R.M.; Goldfarb, R.J.; et al. Controls on the heterogeneous distribution of mineral deposits through time. In *Mineral Deposits and Earth Evolution*; McDonald, I.; Boyce, A.J.; Butler, I.B.; et al., Eds.; Geological Society, London, Special Publications, 248; Geological Society of London: Bath, UK, 2005. https://doi.org/10.1144/GSL.SP.2005.248.01.04
18. Litvinenko, V.; Bowbrick, I.; Naumov, I.; et al. Global guidelines and requirements for professional competencies of natural resource extraction engineers: Implications for ESG principles and sustainable development goals. *J. Clean. Prod.* **2022**, *338*, 130530. https://doi.org/10.1016/j.jclepro.2022.130530
19. Charles, N.; Lefebvre, G.; Tuloup, R.; et al. Mineral resource abundance: An assessment methodology for a responsible use of mineral raw materials in downstream industries. *Sustainability* **2023**, *15*, 16783. https://doi.org/10.3390/su152416783
20. Müller, D.; Groves, D.I.; Santosh, M.; et al. Critical metals: Their mineral systems and exploration. *Geosyst. Geoenviron.* **2025**, *4*, 100323. https://doi.org/10.1016/j.geogeo.2024.100323
21. Nsakabwebwe, C.; Wang, F.; Pandey, A.; et al. Status of critical battery metals recovery from various sources and the prospect of the next generation precursor of cathode active materials: A review. *Sep. Purif. Technol.* **2026**, *387*, 136519. https://doi.org/10.1016/j.seppur.2025.136519
22. Farand, C. EU refuses to review "Strategic" mineral projects for energy transition. *Climate Home News* **2025**.
23. Graedel, T.E.; Allwood, J.; Birat, J.P.; et al. Recycle spent batteries. *Nat. Energy* **2019**, *4*, 425–426.
24. Koese, M.; Parzer, M.; Sprecher, B.; et al. Self-sufficiency of the European Union in critical raw materials for e-mobility. *Resour. Conserv. Recycl.* **2025**, *212*, 108009. https://doi.org/10.1016/j.resconrec.2024.108009
25. Halada, K.; Shimada, M.; Ijima, K. Forecasting of the consumption of metals up to 2050. *Mater. Trans.* **2008**, *49*, 402–410, https://doi.org/10.2320/matertrans.ML200704
26. Watari, T.; McLellan, B.C.; Ogata, S.; et al. Analysis of potential for critical metal resource constraints in the International Energy Agency's long-term low-carbon energy scenarios. *Minerals* **2018**, *8*, 156. https://doi.org/10.3390/min8040156
27. Schodde, R.; Guj, P. Nickel: A tale of two cities. *Geosyst. Geoenviron.* **2025**, *4*, 100356. https://doi.org/10.1016/j.geogeo.2025.100356
28. Sundberg, U. Ecological economics of the Swedish baltic empire: An essay on energy and power, 1560–1720. *Ecol. Econ.* **1992**, *5*, 51–72. https://doi.org/10.1016/0921-8009(92)90020-S
29. Veress, E.; Andersson, J.B.H.; Popova, I.; et al. Three-dimensional geologic modeling of the Kiruna Mining District, Sweden: Insights into the crustal architecture and structural controls on iron oxide-apatite mineralization. *Econ. Geol.* **2024**, *119*, 1089–1113. https://doi.org/10.5382/econgeo.5080
30. Donges, A. Import dependence and strategic war planning – The German iron and steel industry, 1933–1945. *Int. Hist. Rev.* **2024**, *46*, 486–499. https://doi.org/10.1080/07075332.2024.2323490
31. Dobney, F.J. Stockpiling and shortages. *Soc. Sci. Q.* **1976**, *57*, 455–465.
32. Jordan, A.A.; Kilmarx, R.A.; Haendel, D. The U.S. strategic minerals stockpile: Remedy for increasing vulnerability? *Comp. Strategy* **1979**, *1*, 307–331. https://doi.org/10.1080/01495937908402586
33. Fukuyama, F. The end of history? *The National Interest* **1989**, 3–18.
34. Bardi, U.; Jakobi, R.; Hettiarachchi, H. Mineral resource depletion: A coming age of stockpiling? *Biophys. Econ. Resour. Qual.* **2016**, *1*, 4. https://doi.org/10.1007/s41247-016-0004-x
35. Chen, B.; Xiong, R.; Li, H.; et al. Pathways for sustainable energy transition. *J. Clean. Prod.* **2019**, *228*, 1564–1571. https://doi.org/10.1016/j.jclepro.2019.04.372
36. Wehbi, H. Powering the future: An integrated framework for clean renewable energy transition. *Sustainability* **2024**, *16*, 135594. https://doi.org/10.3390/su16135594
37. Zhang, D.; Kong, Q. Green energy transition and sustainable development of energy firms: An assessment of renewable energy policy. *Energy Econ.* **2022**, *111*, 106060. https://doi.org/10.1016/j.eneco.2022.106060
38. Kelley, K.D.; Huston, D.; Peter, J. Toward an Effective Global Green Economy: The Critical Minerals Mapping Initiative (CMMI). *SGA News* **2021** *48*, 1–5. https://pubs.usgs.gov/publication/70222575
39. Shankar, S.; Reuther, A. Trends in energy estimates for computing in AI/machine learning accelerators, supercomputers, and compute-intensive applications. In *Proceedings of the 2022 IEEE High Performance Extreme Computing Conference (HPEC), September 2022*; IEEE: Waltham, MA, USA, 2022; pp. 1–8.
40. Chen, X.; Wang, X.; Colacelli, A.; et al. Electricity demand and grid impacts of AI data centers: Challenges and prospects, *arXiv* **2025**, arXiv:2509.07218.
41. Nana, R.T.; Tadonki, C.; Dokladal, P.; et al. Power consumption in HPC-AI systems. In *Artificial Intelligence and High Performance Computing in the Cloud*; Zbakh, M.; Essaaidi, M.; Tadonki, C.; et al., Eds.; Lecture Notes in Networks and Systems; Springer Nature: Cham, Switzerland, 2024; Volume 1220, pp. 89–116. ISBN 978-3-031-78697-6.
42. VDA. Raw Materials for Electromobility. Available online: https://www.vda.de/en/topics/economic-policy/raw-materials (accessed on 6 February 2026).
43. Morozovska, K.; Bragone, F.; Svensson, A.X.; et al. Trade-offs of wind power production: A study on the environmental implications of raw materials mining in the life cycle of wind turbines. *J. Clean. Prod.* **2024**, *460*, 142578. https://doi.org/10.1016/j.jclepro.2024.142578
44. Venditti, B. A breakdown of the critical metals in a smartphone. *MINING.COM* **2021**.
45. Liventseva, H. *The Mineral Resources of Ukraine*; Ilustre Colegio Oficial de Geólogos: Madrid, Spain, 2022.
46. Franks, D.M.; Rogers, P.; Weldegiorgis, F.; et al. How the rush for critical minerals is neglecting human needs. *Nature* **2025**, 647, 33–

36. https://doi.org/10.1038/d41586-025-03574-8

47. Groves, D.I.; Santosh, M.; Müller, D. Is net zero 2050/2060 a sensible forward-looking pathway for human civilization? A geological long-term perspective. *Gondwana Res.* **2025** *152*, 4–17. https://doi.org/10.1016/j.gr.2025.04.006
48. Saban, K.E.; Wiens, J.J. Unpacking the extinction crisis: Rates, patterns and causes of recent extinctions in plants and animals. *Proc. R. Soc. B-Biol. Sci.* **2025**, *292*, 20251717. https://doi.org/10.1098/rspb.2025.1717
49. Morrison, C. Climate change is not causing mass extinctions, says Bombshell Royal Society Paper – Watts up with that? Available online: https://wattsupwiththat.com/2026/01/21/climate-change-is-not-causing-mass-extinctions-says-bombshell-royal-society-paper/ (accessed on 8 February 2026).
50. Watari, T.; Nansai, K.; Nakajima, K. Major metals demand, supply, and environmental impacts to 2100: A critical review. *Resour. Conserv. Recycl.* **2021**, *164*, 105107. https://doi.org/10.1016/j.resconrec.2020.105107
51. Schodde, R. The global shift to undercover exploration – How fast? how effective? – Minex Consulting. In *Society of Economic Geologists 2014 Conference, 30 September 2014*; Society of Economic Geologists / MinEx Consulting: Keystone, CO, USA, 2014.
52. Schodde, R. Mineral deposit exploration—discovery trends: 1900–2023. In *Geology and Mining: Evolution of Best Practice*; Wood AO, D., Hedenquist, J., Eds.; Society of Economic Geologists: Littleton, CO, USA, 2025. ISBN 978-1-62949-158-5.
53. Klayme, T.; Gokmenoglu, K.K.; Rustamov, B. Economic policy uncertainty, COVID-19 and corporate investment: Evidence from the gold mining industry. *Resour. Policy* **2023**, *85*, 103787. https://doi.org/10.1016/j.resourpol.2023.103787
54. Trench, A.; Baur, D.; Ulrich, S.; et al. Gold production and the global energy transition—A perspective. *Sustainability* **2024**, *16*, 5951. https://doi.org/10.3390/su16145951
55. Desal, P. Record Copper Price Signals Accelerating Race for Supplies. Reuters available online: https://www.reuters.com/world/americas/record-copper-price-signals-accelerating-race-supplies-2026-01-05/ (accessed on 6 February 2026).
56. Cheng, E. China to Restrict Silver Exports, Echoing Rare Earths Playbook. Available online: https://www.cnbc.com/2025/12/31/china-silver-export-controls-2026-us-economy-prices-rare-earths-critical-minerals-xag-metals.html (accessed on 6 February 2026).
57. Murray, C. Price of Silver Surges—Surpasses $80—Following Jobs Report. Available online: https://www.forbes.com/sites/conormurray/2026/01/09/price-of-silver-surges-friday-surpasses-80-following-weak-job-creation/ (accessed on 6 February 2026).
58. Zhou, J.; Månberger, A. *Critical Minerals and Great Power Competition: An Overview*; Stockholm International Peace Research Institute: Stockholm, Sweden, 2024.
59. Eliseo, J. Why Australian investors should add silver to their portfolio. Available online: https://search.informit.org/doi/ 10.3316/informit.T20250221000102 91984869319 (accessed on 6 February 2026).
60. Metiu, N. Global financial transmission of geopolitical risk shocks. *SSRN 5195860* **2025**. https://doi.org/doi.org/10.2139/ssrn.5195860
61. Naimish, J.M.; Shah, D.N.K. Commodity market interactions: Evaluating gold and silver price moments and their correlations. *Gap Gyan-Glob. J. Soc. Sci.* **2025**, *VIII*, 24–28.
62. Nkuna, R.; Ijoma, G.N.; Matambo, T.S.; et al. Accessing metals from low-grade ores and the environmental impact considerations: A review of the perspectives of conventional versus bioleaching strategies. *Minerals* **2022**, *12*, 506. https://doi.org/10.3390/min12050506
63. Teseletso, L.S.; Adachi, T. Future availability of mineral resources: ultimate reserves and total material requirement. *Miner. Econ.* **2023**, *36*, 189–206, https://doi.org/10.1007/s13563-021-00283-2
64. Trading Economics. Metal Price Charts. Available online: https://tradingeconomics.com/commodity/copper (accessed on 6 February 2026).
65. Colgan, J.D.; Gard-Murray, A.S.; Hinthorn, M. Quantifying the value of energy security: How Russia's invasion of Ukraine exploded Europe's fossil fuel costs. *Energy Res. Soc. Sci.* **2023**, *103*, 103201. https://doi.org/10.1016/j.erss.2023.103201
66. Crebo-Rediker, H.E. What's the deal with Trump's Ukraine mineral agreement? Council on Foreign Relations. Available online: https://www.cfr.org/articles/whats-deal-trump-ukraine-mineral-agreement (accessed on 8 February 2026).
67. Mishra, V. UN Hails DR Congo-Rwanda Peace Deal amid Ongoing Hostilities in the East. UN News. Available online: https://news.un.org/en/story/2025/12/1166527 (accessed on 8 February 2026).
68. Makumenu, E.; Cyuzuzu, S.; Booty, N.; et al. Trump Hosts Signing of Peace Deal between Leaders of DR Congo and Rwanda. Available online: https://www.bbc.com/news/articles/cjrjn88jqn4o (accessed on 6 February 2026).
69. S&P Global Major Nickel Discoveries Remain Scarce amid Looming Supply Deficits. Available online: https://www.spglobal.com/market-intelligence/en/news-insights/research/major-nickel-discoveries-remain-scarce-amid-looming-supply-deficits (accessed on 6 February 2026).
70. Mills, R. *Indonesia and China Killed the Nickel Market*. MINING.COM: Toronto, ON, Canada, 2024.
71. Silva, E. *Indonesia's Nickel Processing Boom Raises Questions Over Tailings Disposal*; S&P Global Market Intelligence: New York, NY, USA, 2023.
72. Milne, P.; Johanson, S. *Indonesian Nickel Boom Claims Another Wa Mine, and Hundreds of Jobs*; The Age: Melbourne, VIC, Australia, 2024.
73. Keen, K. *Weak Nickel Prices, Oversupply, Hobble Miners with Closures, Cuts*; S&P Global Market Intelligence: New York, Ny, USA, 2024
74. Nangoy, F.; Suroyo, G.; Christina, B.; et al. Like musk, nickel-rich Indonesia has high electric vehicle ambitions. *Reuters* **2023**.
75. Warburton, E. Nationalist enclaves: Industrialising the critical mineral boom in Indonesia. *Extr. Ind. Soc.* **2024**, *20*, 101564. https://doi.org/10.1016/j.exis.2024.101564
76. Maynard, J.B. *Geochemistry of Sedimentary Ore Deposits*; Springer Science & Business Media: New York, NY, USA, 2012. ISBN 978-1-4613-9493-8.
77. The White House. *Immediate Measures to Increase American Mineral Production*; White House: Washington, DC, USA, 2025.
78. Baskaran, G. China's New rare Earth and Magnet Restrictions Threaten U.S. Defense Supply Chains. Available online: https://www.csis.org/analysis/chinas-new-rare-earth-and-magnet-restrictions-threaten-us-defense-supply-chains (accessed on 8 February 2026).
79. Baskaran, G.; Horvath, K. Unpacking the U.S.-Australia Critical Minerals Framework Agreement. Available online: https://www.csis.org/analysis/unpacking-us-australia-critical-minerals-framework-agreement (accessed on 6 February 2026).
80. Baskaran, G.; Schwartz, M. What to Know About the Signed U.S.–Ukraine Minerals Deal. Available online: https://www.csis.org/analysis/what-know-about-signed-us-ukraine-minerals-deal (accessed on 6 February 2026).
81. Kirby, P.; FitsGerald, J.; Geoghegan, T. Seven Takeaways from Ukraine Minerals Deal. Available online: https://www.bbc.com/news/articles/c5yg456mzn8o (accessed on 6 February 2026).
82. Gilder Lehrman Institute of American History. The Monroe Doctrine, 1823. Available online: https://www.gilderlehrman.org/history-resources/spotlight-primary-source/monroe-doctrine-1823 (accessed on 6 February 2026).

83. Allen, J. Pro-Colonialism Talking Points Get a Boost from Top Trump Aide Stephen Miller. Available online: https://www.nbcnews.com/politics/trump-administration/colonialism-talking-points-top-trump-aide-stephen-miller-rcna252437 (accessed on 7 January 2026).

84. Borger, J. Trump's territorial ambition: New imperialism or a case of the emperor's new clothes? *The Guardian* **2026**.

85. Hooper, R. Why Does the United States Want to Buy Greenland? Available online: https://www.newscientist.com/article/2510896-why-does-the-united-states-want-to-buy-greenland/ (accessed on 6 February 2026).

86. Sheerin, J.; Pomeroy, G. US Discussing Options to Acquire Greenland Including Using Military - White House. Available online: https://www.bbc.com/news/articles/cwyg1jg8xkmo (accessed on 6 February 2026).

87. Alexander, R. Extreme weather: The IPCC's changing tune. *Glob. Warm. Policy Found. Rep.* **2022**, *54*, 1–30.

88. Ettinger, J.; Walton, P.; Painter, J.; et al. Examining contrasting influences of extreme weather experiences on individual climate activism. *Glob. Environ. Psychol.* **2024**, *2*, e10829. https://doi.org/10.5964/gep.10829

89. Tu, S.; Hu, Z.; Liang, M.; et al. Decreasing trend in destructive potential of tropical cyclones in the South Indian Ocean since the mid-1990s. *Commun. Earth Environ.* **2024**, *5*, 543. https://doi.org/10.1038/s43247-024-01683-2

90. Schinaia, C. Catastrophism and media catastrophic images. In *Against Catastrophism*; Routledge: London, UK, 2025.

91. Menton, F. Suppressing Climate Dissent Cannot Prevent Reality From Asserting Itself. Available online: https://www.manhattancontrarian.com/blog/2026-1-17-suppressing-climate-dissent-cannot-prevent-reality-from-asserting-itself (accessed on 6 February 2026).

92. Montford, A. The Antics of the Climate Clique. Available online: https://www.netzerowatch.com/all-news/the-climate-clique (accessed on 6 February 2026).

93. Voelkel, J.G.; Ashokkumar, A.; Abeles, A.T.; et al. A registered report megastudy on the persuasiveness of the most-cited climate messages. *Nat. Clim. Change* **2026**, *16*, 214–225. https://doi.org/10.1038/s41558-025-02536-2

94. Yeo, S. How the Largest Environmental Movement in History was Born. Available online: https://www.bbc.com/future/article/20200420-earth-day-2020-how-an-environmental-movement-was-born (accessed on 6 February 2026).

95. The Guardian. Seven just stop oil activists convicted over london road blockade. *The Guardian* **2023**.

96. CBS News. Climate Activists Glue Themselves at Germany Airport to Protest Pollution Caused by Flying. Available online: https://www.cbsnews.com/news/climate-activists-glue-munich-germany-airport-protest-pollution-flying/ (accessed on 6 February 2026).

97. Voice of America. Climate Activists Glue Themselves at Munich Airport. Available online: https://www.voanews.com/a/climate-activists-glue-themselves-at-munich-airport/7617613.html (accessed on 6 February 2026).

98. Gosselin, P. Berlin's Terror-Blackout Enters 4th Day As Tens Of Thousands Suffer In Cold Without Heat! Available online: https://wattsupwiththat.com/2026/01/06/berlins-terror-blackout-enters-4th-day-as-tens-of-thousands-suffer-in-cold-without-heat/ (accessed on 6 February 2026).

99. Tanno, S.; Shukla, S.; Kappeler, I. Thousands of Berliners Lost Power for Days after Climate Activists Struck. Here's What Happened. CNN available online: https://edition.cnn.com/2026/01/07/europe/berlin-power-outage-intl (accessed on 6 February 2026).

100. Yu, S.; Cui, R.; McJeon, H.; et al. Five Strategies to Achieve China's 2060 Carbon Neutrality Goal. Available online: https://www.efchina.org/Reports-en (accessed on 6 February 2026)

101. Nova, J. German Chancellor Admits Shutting Nuclear Plants Was a "Serious Strategic Mistake" — Will Rebuild Nuclear. JoNova. Available online: https://joannenova.com.au/2026/01/german-chancellor-admits-shutting-nuclear-plants-was-a-serious-strategic-mistake-will-rebuild-nuclear/ (accessed on 6 February 2026).

102. Kliszcz, E. Germany's Merz Says Nuclear Energy Exit Was 'Strategic Mistake'. Available online: https://tvpworld.com/91076865/merz-germanys-nuclear-exit-was-strategic-mistake (accessed on 6 February 2026).

103. Lemaire, C. Germany's Shut down of Nuclear Plants a 'Huge Mistake', Says Merz. Available online: https://brusselssignal.eu/2026/01/germanys-shut-down-of-nuclear-plants-a-huge-mistake-says-merz/ (accessed on 6 February 2026).

104. The Economic Times. "Serious Strategic Blunder!": Trump's 2018 Warning Resurfaces as Merz Slams Germany's Nuclear Exit. Available online: https://economictimes.indiatimes.com/news/international/world-news/serious-strategic-blunder-trumps-2018-warning-resurfaces-as-merz-slams-germanys-nuclear-exit/videoshow/126614610.cms?from=mdr (accessed on 6 February 2026).

105. Chan, S.P.; Oliver, M. Industry Sacrificed over Net Zero Ideology, Says Siemens Energy Boss. Available online: https://www.telegraph.co.uk/business/2026/01/25/industry-sacrificed-over-net-zero-ideology-siemens-energy/ (accessed on 6 February 2026).

106. Zhou, L. Towards sustainability in mineral resources. *Ore Geol. Rev.* **2023**, *160*, 105600. https://doi.org/10.1016/j.oregeorev.2023.105600

107. Rico, M. Mining for Minerals Is Not a European Business. Available online: https://www.investigate-europe.eu/posts/ mining-minerals-not-european-business (accessed on 6 February 2026).

108. Di Sario, F. Critical Raw Materials: EU's Push to Secure Supplies Faces New Challenges amid Rising Geopolitical Tensions. Available online: https://www.theparliamentmagazine.eu/news/article/europes-quest-for-critical-raw-minerals-gains-new-urgency (accessed on 6 February 2026).

109. Pim, J.E. The securitization of minerals in the EU: Why Europe is not immune to the resource curse. Available online: https://www.resilience.org/stories/2026-01-06/the-securitization-of-minerals-in-the-eu-why-europe-is-not-immune-to-the-resource-curse/ (accessed on 6 February 2026).

110. Bose, N.; Chiacu, D. In Munich, Vance Accuses European Politicians of Censoring Free Speech. *Reuters* **2025**.

111. Zerka, P. Trump's Culture War on Europe Is Far from over – European Council on Foreign Relations. *ECFR* **2026**.

112. Reuters. Lagarde Walks out of Lutnick Speech in Davos Critical of Europe, Sources Say. Reuters. Available online: https://www.reuters.com/world/us/lutnick-heckled-davos-dinner-hosted-by-blackrocks-fink-ft-reports-2026-01-21/ (accessed on 6 February 2026).

113. D'amato, R.; Salimbeti, A. *Sea Peoples of the Bronze Age Mediterranean c. 1400 BC–1000 BC*; Bloomsbury Publishing: London, UK, 2015; Volume 204.

114. Robbins, M. *Collapse of the Bronze Age: The Story of Greece, Troy, Israel, Egypt, and the Peoples of the Sea*; iUniverse: Lincoln, NE, USA, 2001. ISBN 978-0-595-13664-3.