

The Energy Transition, Critical Raw Materials and Geopolitics: a complex mix !

FRDO, Brussels

René Kleijn · 30 October 2026



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Critical raw materials: the spices of technological societies

- The energy transition
 - Batteries (storage and EVs), solar cells, windturbines, (smart and super) grid etc
- Digital infrastructure
 - Servers, chips, hard drives, photonics, edge computing, quantum computing, AI etc
- Defence
 - Radar, guided missiles, lasers, drones, electronics, night vision, camouflage
- Automation, robotization
 - Humanoids etc.



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What is critical ? A moving target !

- Critical: important for the economy AND potentially supply constraints
- Material basis of society changes rapidly, so what is important ?
 - CRT, car catalysts are out while battery materials are in
 - battery chemistries change rapidly (new CATL batteries are cheap (10\$/kWh) and contain no Li, Co, Ni Mn ...)
- Trade relations shift rapidly in an unstable world so what are safe supply routes?
 - Russian gas
 - Conflict in the Middle East
 - US tariffs



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TREND

More complex products

RESULT

More and more different elements in everyday products



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elements used in the production of computerchips 1980s: 12 of 92 elements

H																	He		
Li	Be											B	C	N	O	F	Ne		
Na	Mg											Al	Si	P	S	Cl	Ar		
K	Ca	Y	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
Rb	Sr	La	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
Cs	Ba	Ac	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
Fr	Ra																		
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu			
		Ac	Th	Pa	U														

Data: National Research Council, 2007 / Intel



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elements used in the production of computerchips 1990s: 16 of 92 elements

H																	He		
Li	Be											B	C	N	O	F	Ne		
Na	Mg											Al	Si	P	S	Cl	Ar		
K	Ca	Y	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
Rb	Sr	La	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
Cs	Ba	Ac	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
Fr	Ra																		
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu			
		Ac	Th	Pa	U														

Data: National Research Council, 2007 / Intel



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elements used in the production of computerchips

2000s: 61 of 92 elements

H																	He		
Li	Be											B	C	N	O	F	Ne		
Na	Mg											Al	Si	P	S	Cl	Ar		
K	Ca	Y	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
Rb	Sr	La	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
Cs	Ba	Ac	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
Fr	Ra																		
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu			
		Ac	Th	Pa	U														

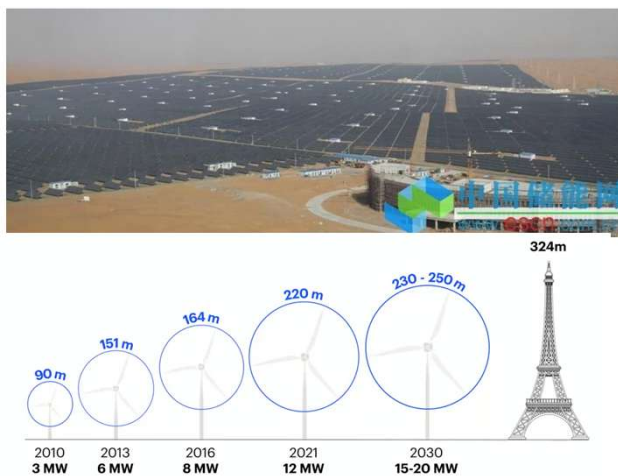
Data: National Research Council, 2007 / Intel



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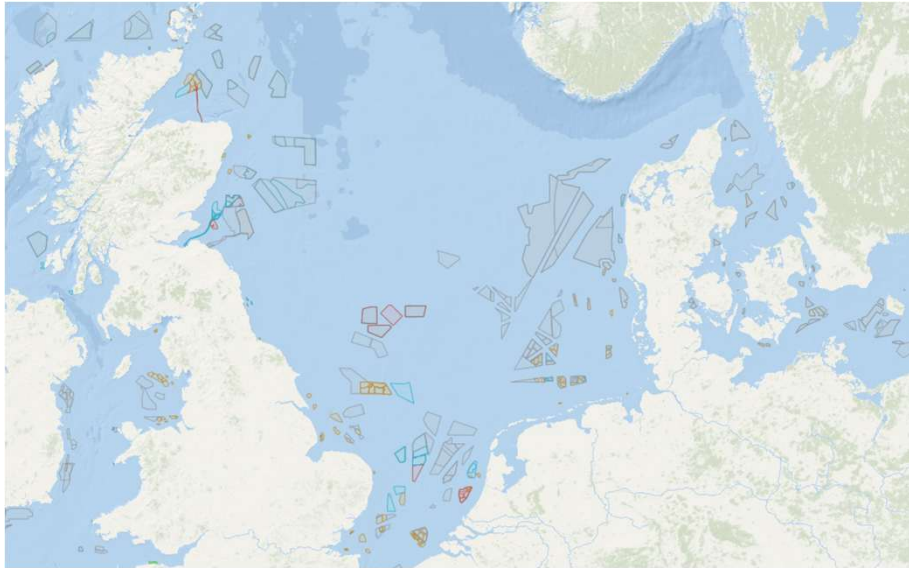
The energy transition creates a demand shock for many (critical) materials



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Planned wind parks



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China Changji-to-Guquan
3300 km, 1100 kV, 12 GW
Direct current
\$ 6 billion



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12 GW crossing the Yangtze River



WWW.NEWS.CN

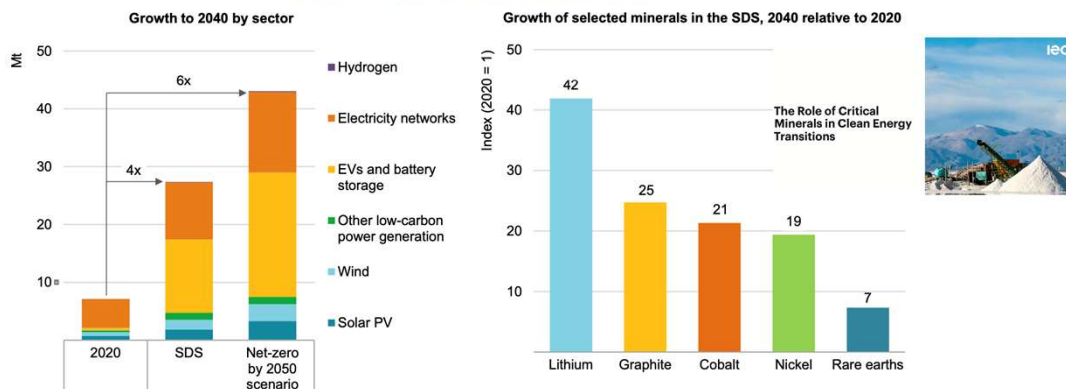


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The energy transition is in fact a commodity / material transition (from fossil fuels to metals)

Mineral demand for clean energy technologies by scenario



IEA. All rights reserved.

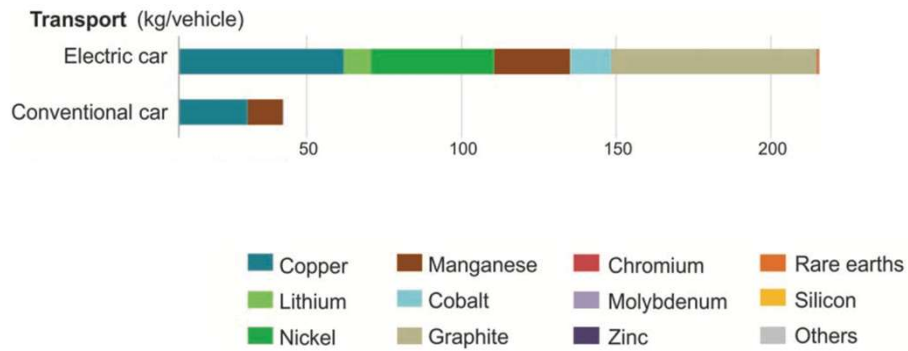
Notes: Mt = million tonnes. Includes all minerals in the scope of this report, but does not include steel and aluminium. See Annex for a full list of minerals.



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EVs contain a wide variety of metals



Eilu et al, 2021, modified from IEA, 2021



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Volkswagen ID4



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Volkswagen ID4



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Battery ID4



Battery 500-900 kg: lithium, nickel, cobalt, manganese, (copper, aluminum, steel)



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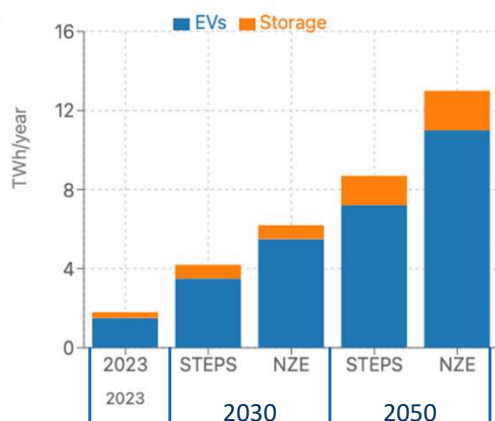


Traction motor ID4



Traction motor: ~30 kg, copper, steel and a few kg magnets (neodymium, praseodymium, dysprosium)

Battery demand expected to increase 5-7 fold till 2050



Datasource: IEA: Global Critical Minerals outlook 2024, p87

Geopolitics & supply security



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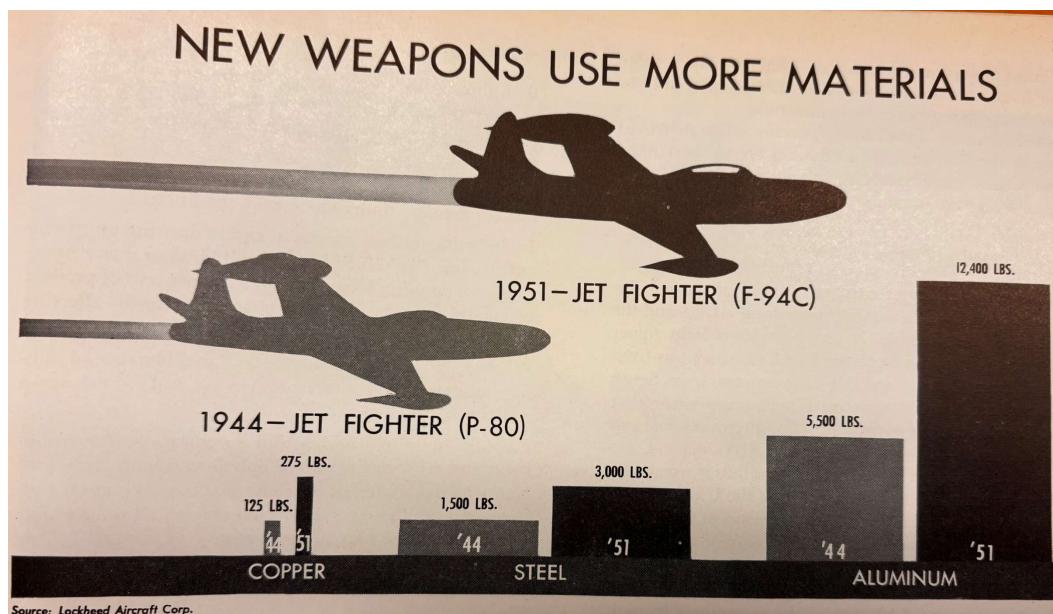


Supply crunch & vulnerable supply chains: COVID, Russian aggression & power politics



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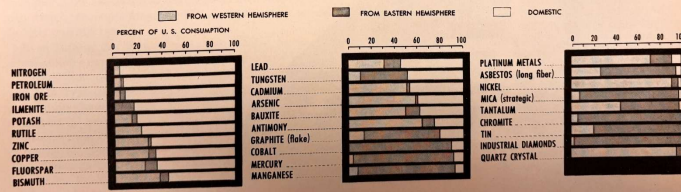


FREE WORLD LIFELINES ARE LONG AND EXPOSED



MINERAL IMPORTS VITAL TO U. S. SECURITY

FOREIGN SOURCES OF 29 PRINCIPAL INDUSTRIAL MINERALS IN 1951

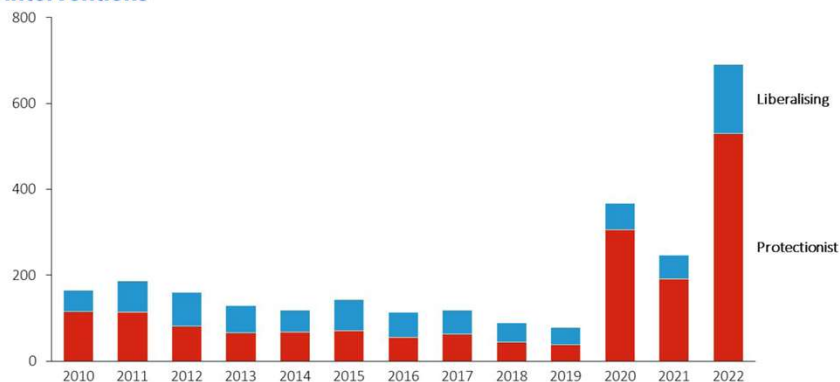


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More protectionism

Trade policy interventions



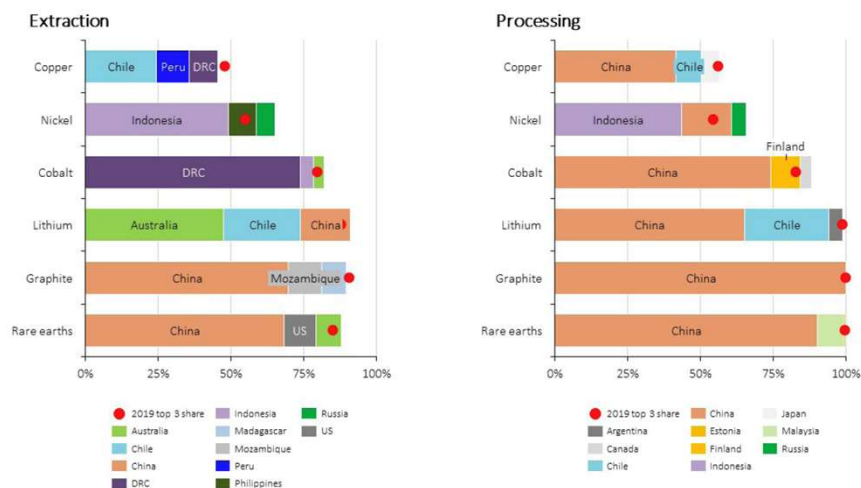
Note: Measures include tariffs, export-related measures, subsidies, contingent trade-protective measures, and trade-related investment measures.

Source: Global Trade Alert, 2024.

The Future of European Competitiveness (The Draghi report), 2024

Concentration of the extraction and processing of critical resources

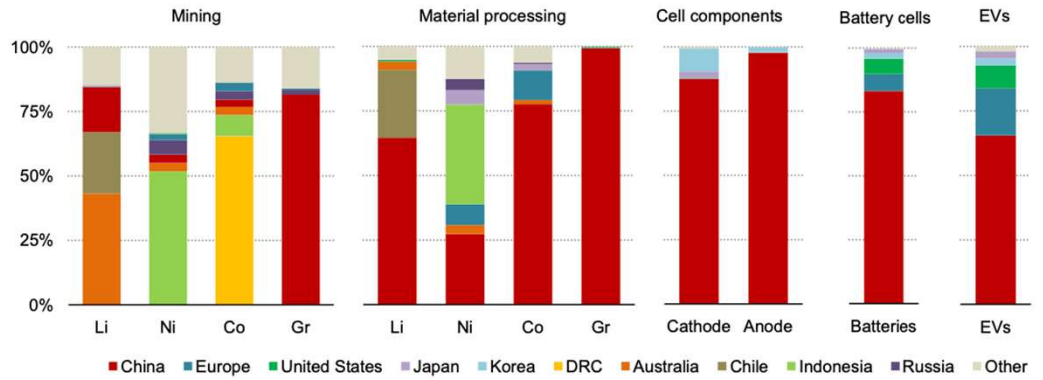
Share of top-three producing countries in total production for selected resources and minerals, 2022



IEA. Based on S&P Global, USGS, Mineral Commodity Summaries and Wood Mackenzie, 2024.

China dominates batteries and EV markets

Geographical distribution of the global EV battery supply chain, 2023



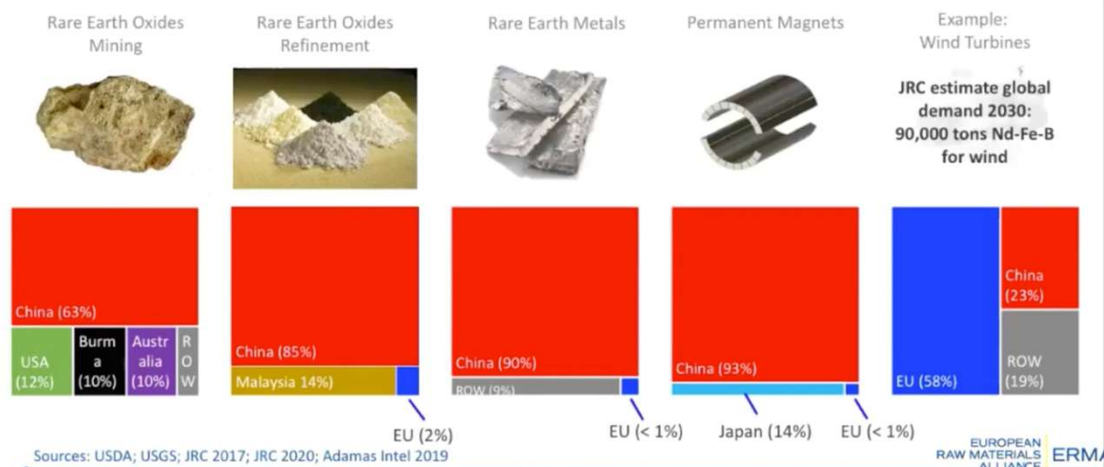
IEA, CC BY 4.0.



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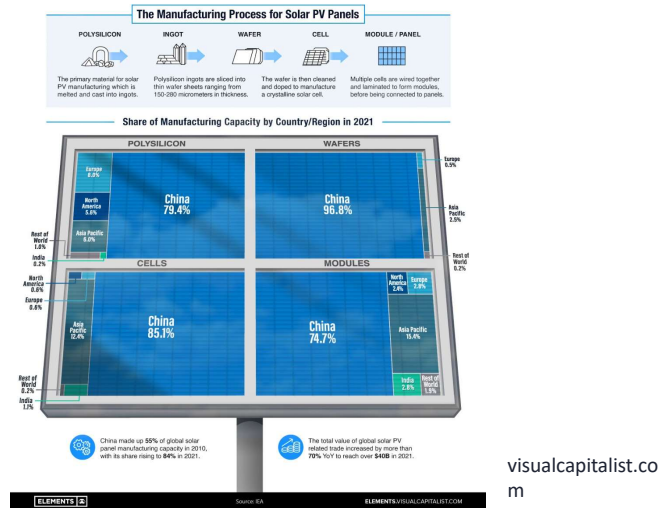
China dominates the magnet supply chain



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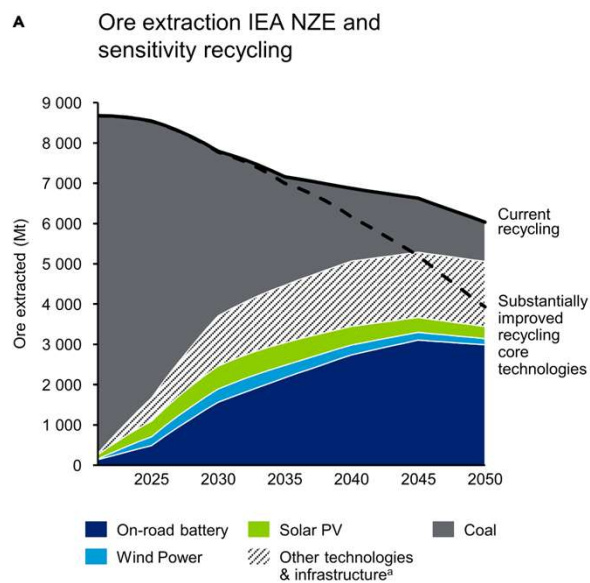
Who Controls the Solar Panel Supply Chain?



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The energy transition requires less mining than the fossil fuel based system !

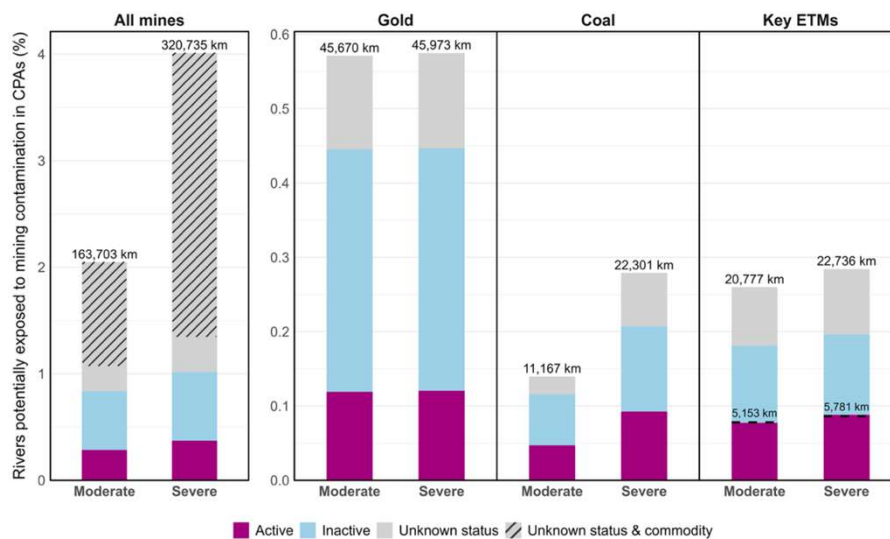


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Nijmens et al, Joule ,2023



Not energy transition minerals but gold and coal cause the highest risk to fresh water ecosystems



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Bras Pirez et al., Global Change Biology 2026



Fostering the urban mine: design is key : act now – harvest later

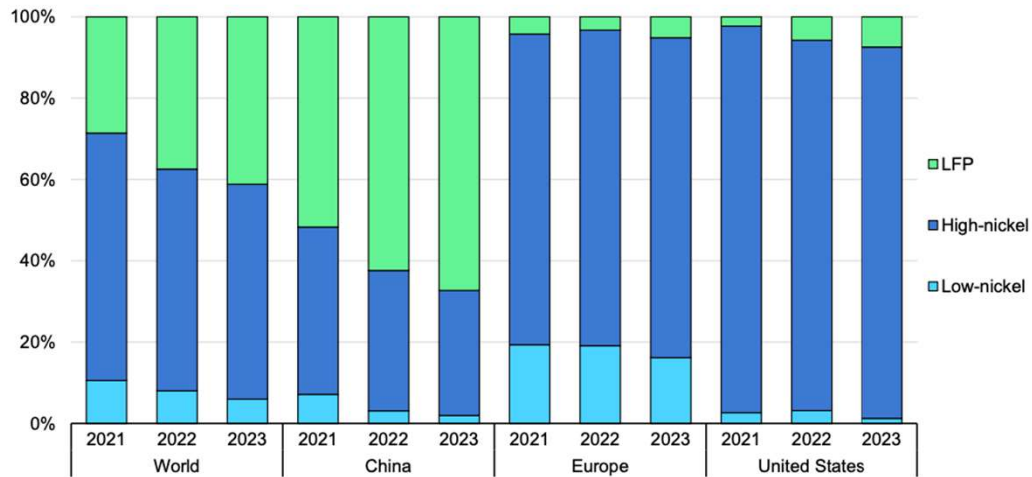


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Technology reduces critical raw materials demand

Share of battery capacity of electric vehicle sales by chemistry and region, 2021-2023



Tesla Model Y structural battery pack with 4680 cells



MUNRO
LIVE

Rare Earth magnets in EV motors



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The need for resilient supply chains



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From *just-in-time* to *just-in-case*

- Resilience comes at a cost:
 - Inventories / buffers / stocks require capital
 - Not only the cheapest supplier but diversity of supply at higher cost
 - Shift from less to more reliable trade partners (bilateral deals US, UK..)
 - Develop alternative (sub-optimal?) product designs / technologies, in case preferred option is not available
 - Substitute rare materials by more common materials (performance?)

So what should Europe do to secure supply ?

- **Self-sufficiency ?**
 - Self-sufficiency $\neq$ strategic autonomy
 - full self-sufficiency is an illusion (and undesirable)
 - Re-shore some supply chains for critical technologies (steel, aluminum, energy, IT) including mining and refining
- **Friend-shoring ?**
 - Bilateral deals with the our friends: Australia, Canada
- **Bilateral deals 'with benefits' with more complex partners ?**
 - Untied Loan Guarantee / Raw Material Guarantee
 - Combine investments in raw material sectors with aid and responsible sourcing
 -
- **Foster the urban mine : circularity !**
- **Develop industrial ecosystems from mine to product for critical supply chains**
- **All of the above** but only works *if* combined with a **level playing field to create industrial ecosystems around CRMs**

This is no longer just economics...

- In a world in geopolitical turmoil, economic dependency becomes a **political issue**
- Economic optimization through **globalization has served us well in the past**
- **Secure and resilient supply and circularity come at a cost**
- But the **costs of shortages, or worse, weaponized resource / tech supply, are much higher !**

Projects



CERA 4in1 - Certification of Mineral Raw Materials for sustainable development in mining

 Groeien met Groen Staal

 PBL Netherlands Environmental Assessment Agency

WERKPROGRAMMA MONITORING & STURING CIRCULAIRE ECONOMIE 2023-2024

