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Water Limits to Global Mineral Production: A Sustainability Perspective

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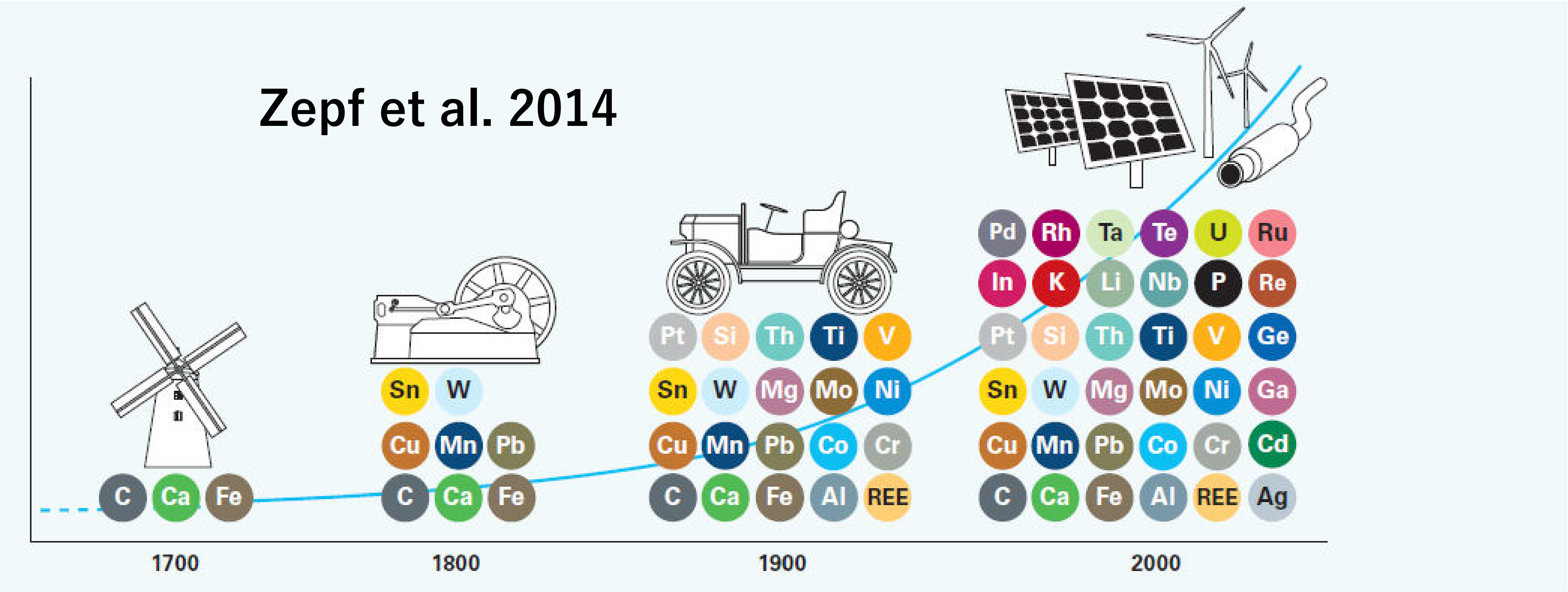
1st - 5th Dec 2025

The XIX World Water Congress, Marrakech, Morocco

How mineral use has expanded over time?



Elements widely used in energy pathways

N.B. Position on the time axis is indicative only

Growing dependence on mineral resources for modern technologies and energy transitions.

Mineral demand in the age of decarbonization

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INSIGHTS

POLICY FORUM

ENERGY

Sustainable minerals and metals for a low-carbon future

Policy coordination is needed for global supply chains

By Benjamin K. Sovacool[1], Saleem H. Ali[2,3,4], Morgan Bazilian[5], Ben Radley[6], Benoit Nemery[7], Julia Okatz[8], Dustin Mulvaney[9]

more than 7100 GW (3). The materials and metals demanded by a low-carbon economy will be immense (4). One recent assessment concluded that expected demand for 14

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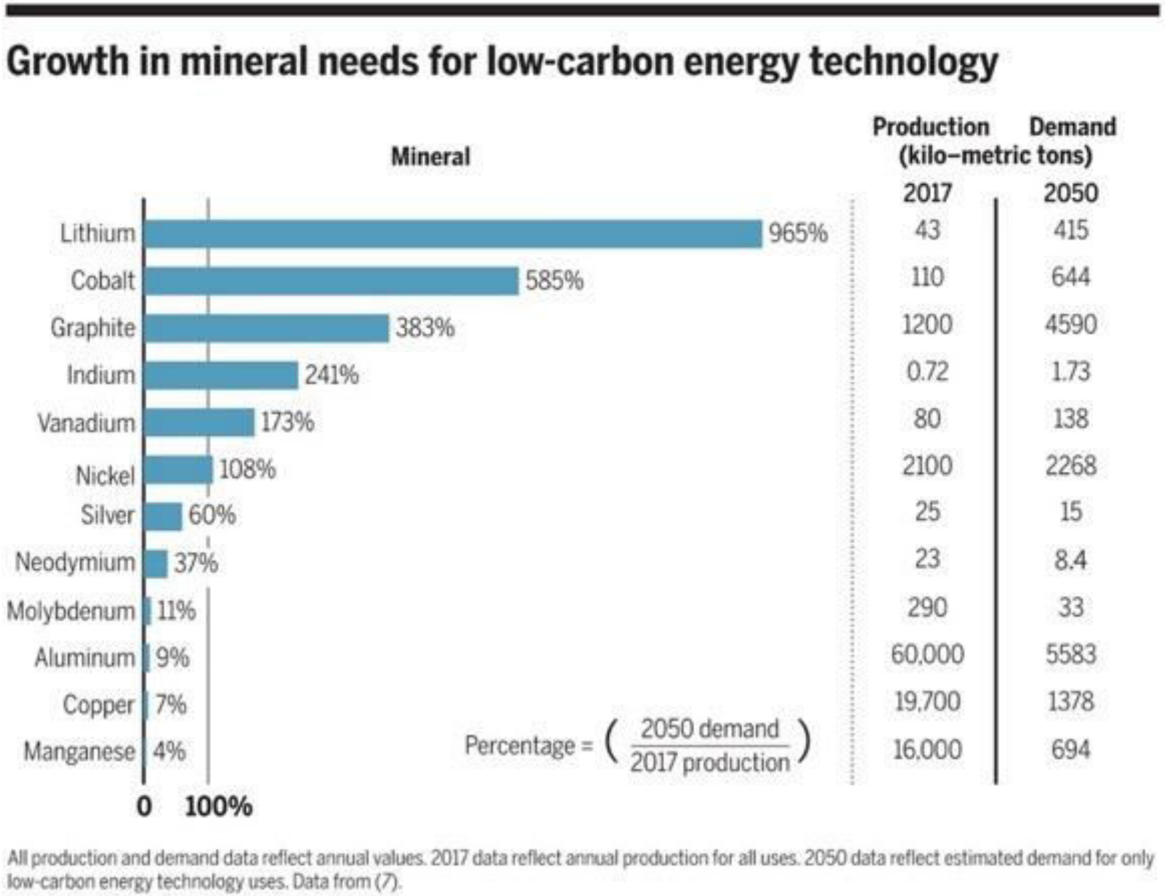


Increasing global demand of minerals for decarbonization requires the urgent sustainable resource governance.

Mineral abundance is not enough

Availability of minerals is not just a matter of geological abundance:

- *Supply disruptions* (e.g., disasters, strikes, geopolitical tensions)
- *Geographical imbalance in resource distribution*
- *Environmental constraints* (e.g., climate change, water, biodiversity, etc.)

Potential of environmental constraints is not well explored.

Issues in mineral production and challenges

Mineral production requires energy (CO_2), water and land use

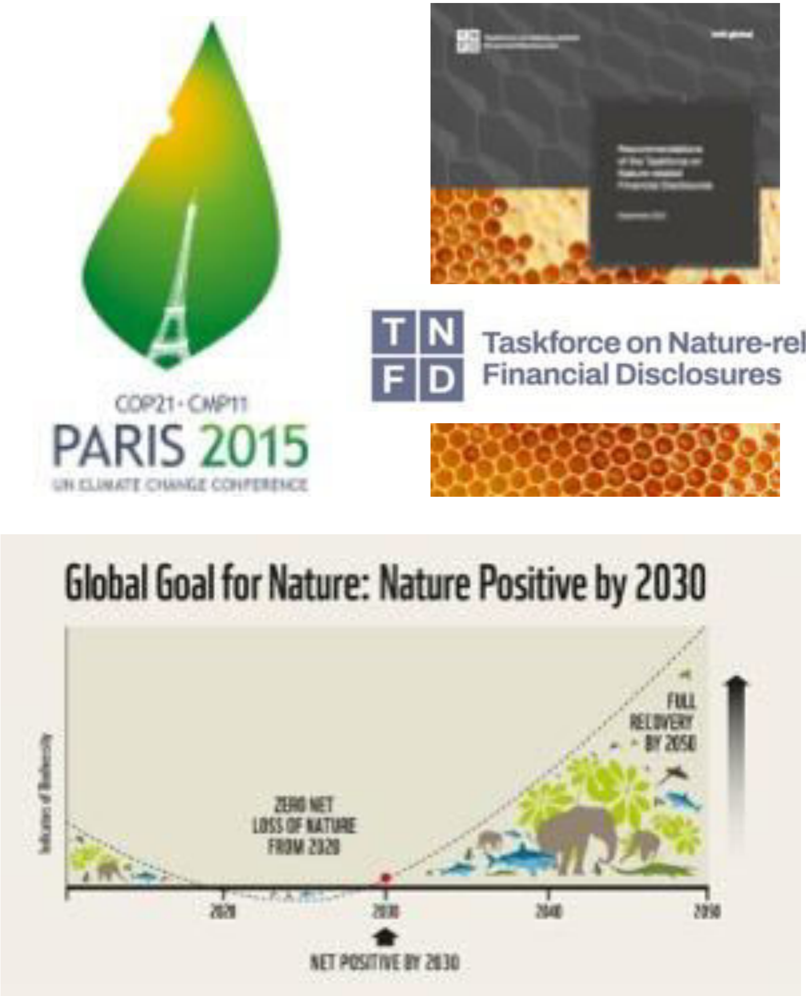
10% of the global total

(at maximum) from metal production

Environmental goals could restrict production!

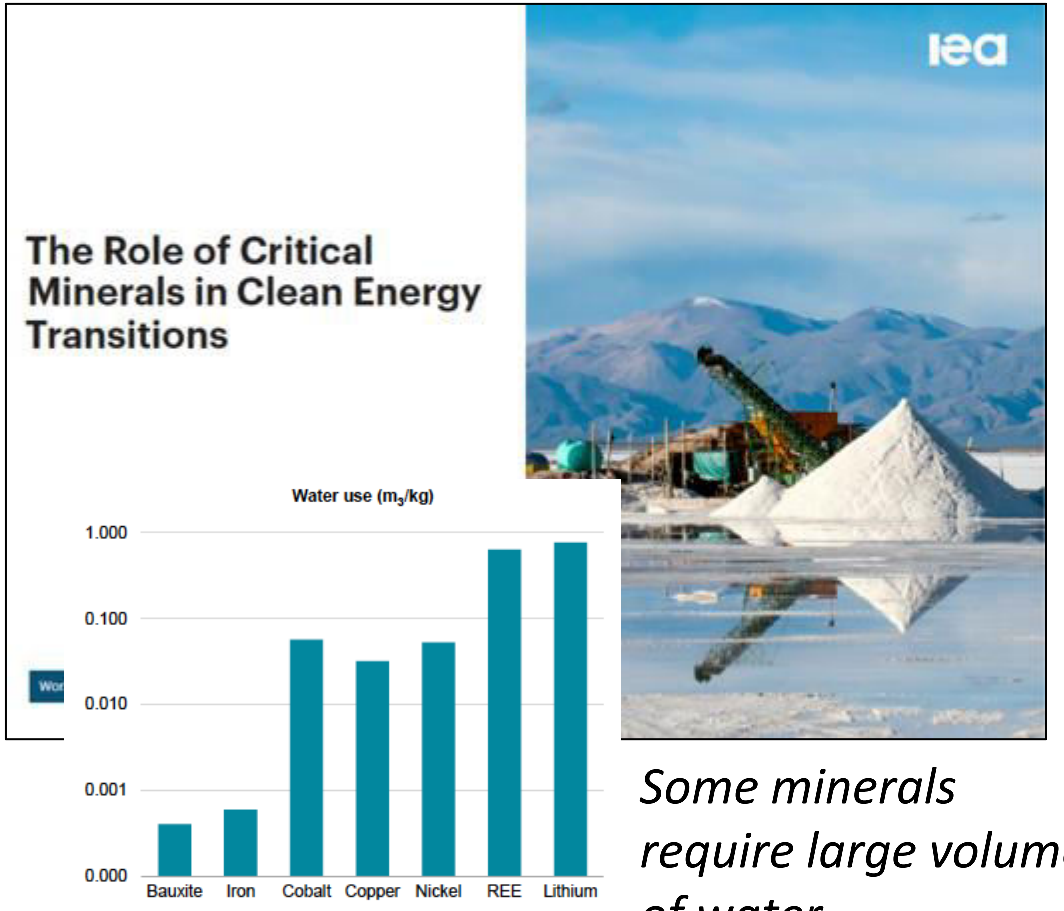
COP21·CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

Taskforce on Nature-related Financial Disclosures



Dependence on water resource

Water associated with minerals production is concerned (the IEA report).



Some minerals require large volume of water.

https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

40% of global population will face water scarcity in 2050

Can we secure water for mineral production?

Objectives

Exploring the sustainable limits of mineral production under the environmental constraints:

Planetary boundary (PB) approach

Define a specific goal for sustainable mineral use

How much minerals can we use under regional water availability as a constraint?

Methods: Planetary boundary-based assessment

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[SNL mining data] ➔ [Water use mapping] ➔ [Overconsumption detection] ➔ [Future projections]

a)

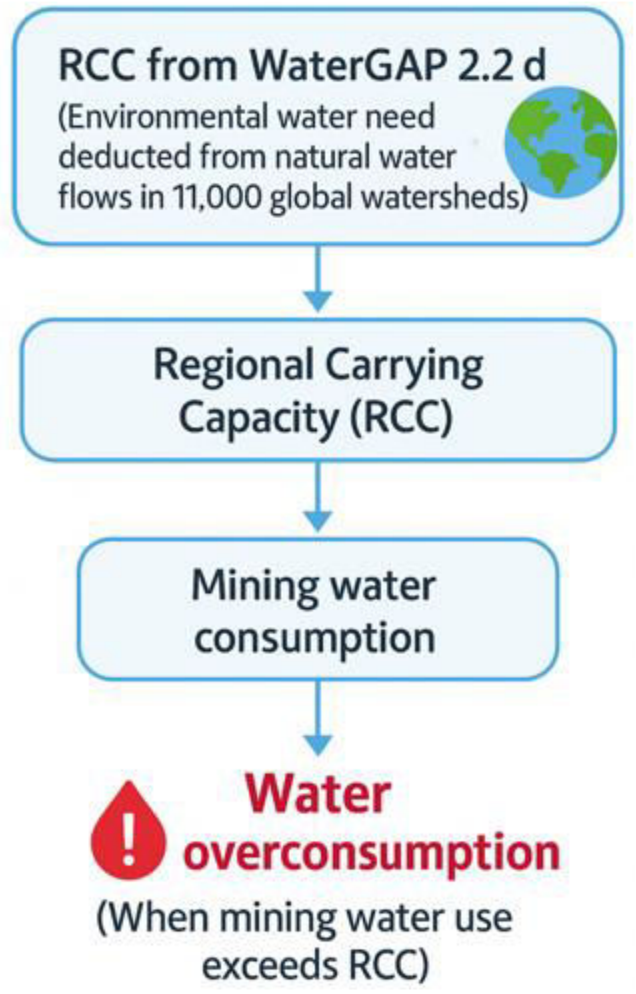
SNL mining data
(3,319 mines; 32 types)

X

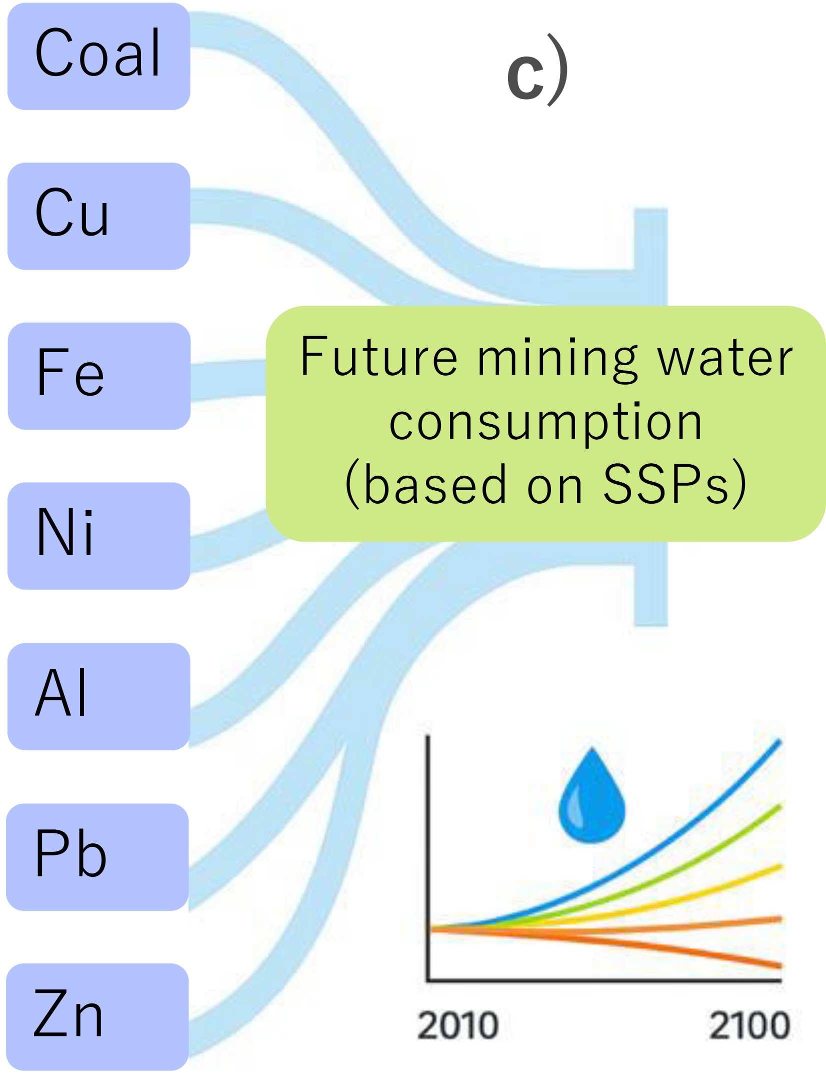
Water consumption intensity
(based on intensive literature review)

Mining water consumption

b)



c)



Methods: How to alleviate overproduction?

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To reduce overproduction where mining exceeds regional water limits, we explored substitution of production to less water-stressed countries through three scenarios.

Scenario 1

Maximum capacity

- Shift production to countries with surplus capacity
- **Based on remaining production capacity**

Scenario 2

Global sustainability

- Prioritize largest mass of overproduction
- **Based on economic competitiveness (RCA)**

Scenario 3

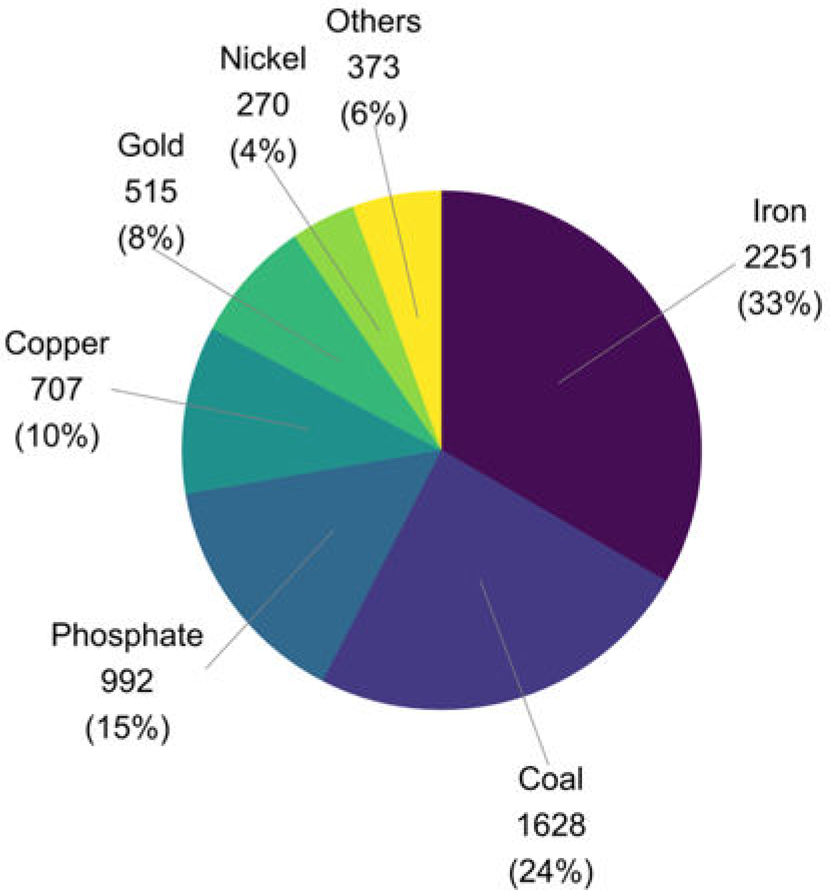
Local sustainability

- Prioritize highest overproduction rate
- **Based on economic competitiveness (RCA)**

Global mining water use: Who uses how much?

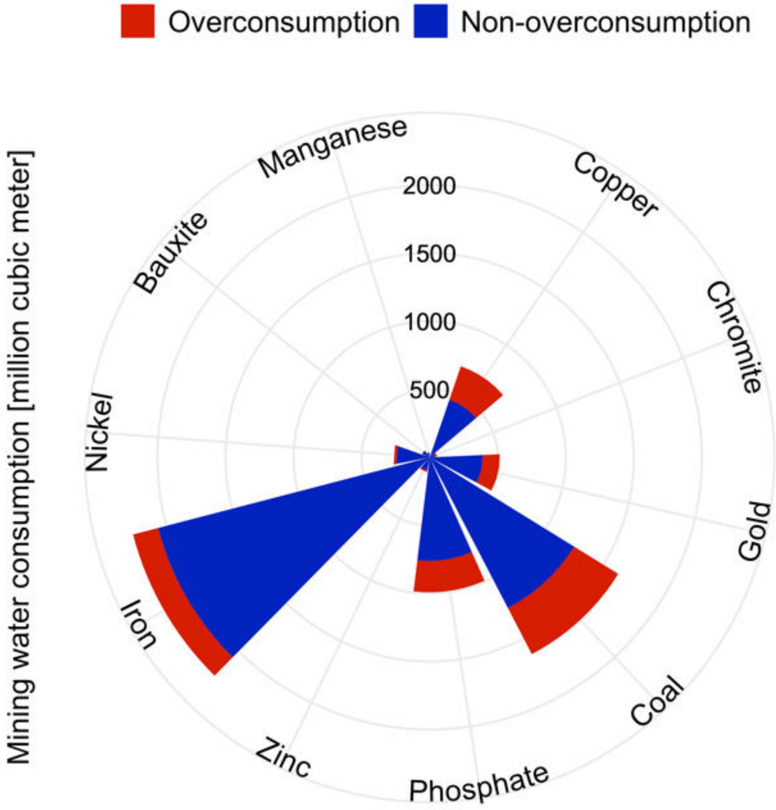
Results

Total mining water use: 6,739 m^3 (around 7% of global industrial use)



=> Iron uses water the most, but…

In terms of regional water availability…

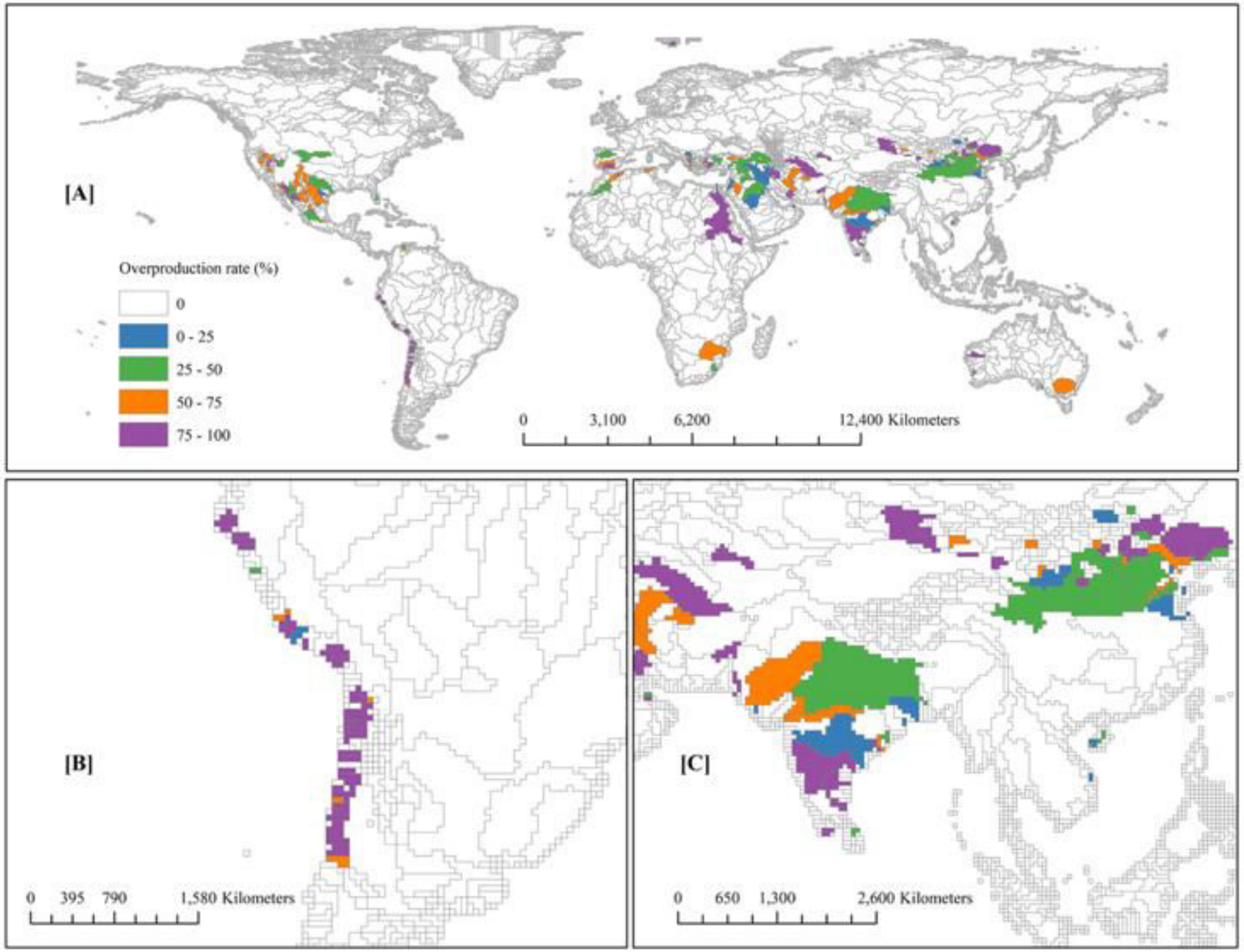


=>Copper is the most concerned:

37% already beyond water limits.

Where are we exceeding water limits?

Results



🌵 **Chile and Peru** emerged as overconsumption hotspots.

📌 **6% of global mining watersheds** exceeded sustainable water use levels.

🔴 **50% of these watersheds** had **extreme overproduction** rates (>75%).

⚠ Overproduction is mainly linked to **Cu (22 sites)**, **Au (14)**, **Fe (11)**, and **Coal (8)**.

What happens to future water stress without any action?

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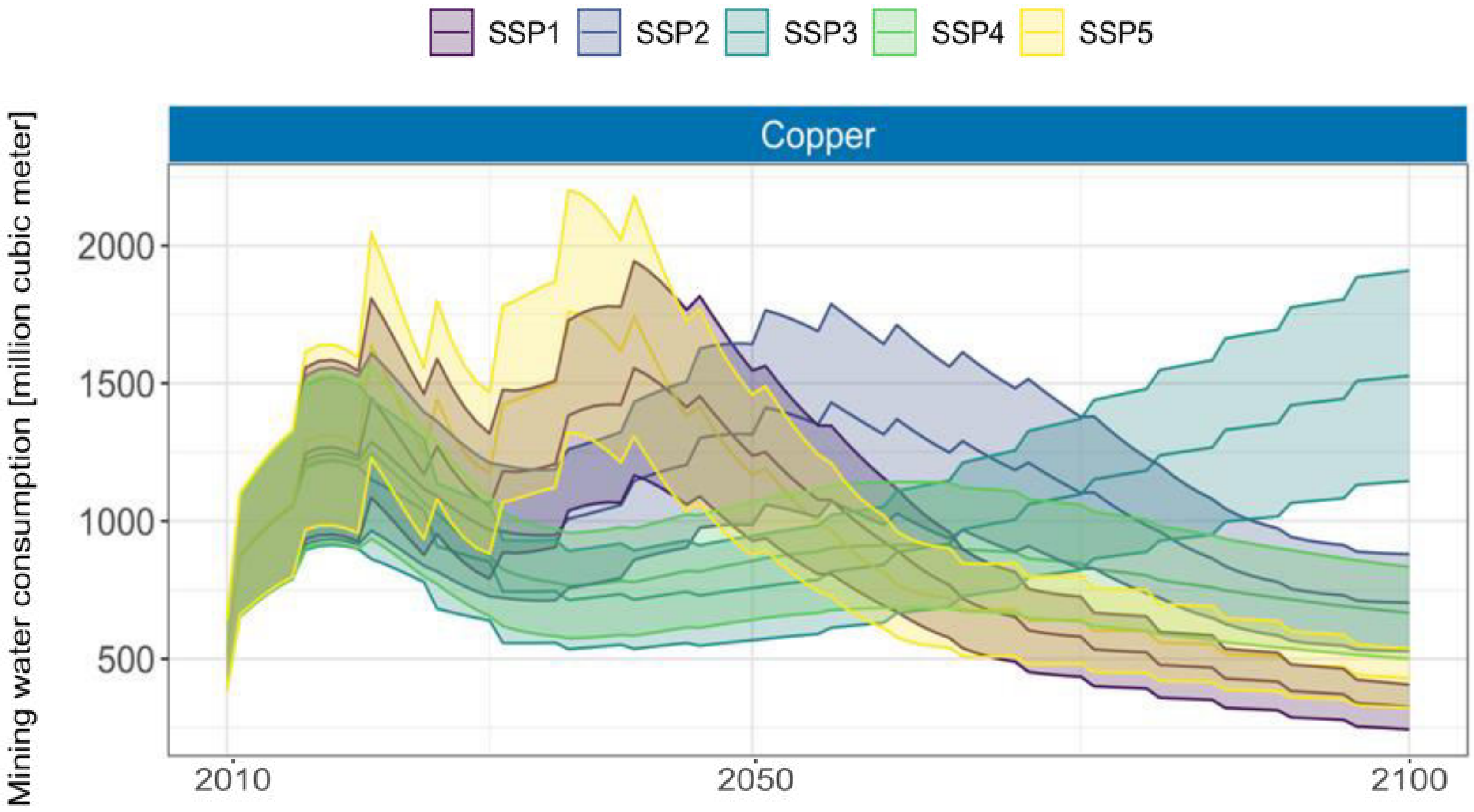
Results



Future mining water use may triple

— even in the sustainability scenario.

Can we alleviate overproduction?

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Results

Rank	Copper							
	BaU		Substitution case 1		Substitution case 2		Substitution case 3	
	Country	Mine production [ton]	Country	Mine production [ton]	Country	Mine production [ton]	Country	Mine production [ton]
1	Chile	5,213,853	Zambia	2,169,181	Chile	2,985,325	Chile	3,172,791
2	Peru	1,177,394	Chile	1,914,560	Zambia	2,169,181	Zambia	2,169,181
3	USA	1,133,574	Canada	1,581,236	Canada	1,581,236	Canada	1,581,236
4	Australia	876,754	Poland	1,346,535	Poland	1,346,535	Poland	1,346,535
5	Indonesia	849,127	Dem. Rep. Congo	1,053,355	Australia	876,754	Australia	876,754
6	Zambia	685,292	Australia	774,573	Indonesia	738,349	Indonesia	738,349
7	China	654,116	Indonesia	738,349	China	654,116	China	654,116
8	Russia	574,243	USA	581,783	USA	581,783	USA	581,783
9	Canada	499,547	China	574,046	Russia	560,543	Russia	560,543
10	Poland	425,400	Russia	560,543	Peru	451,075	Peru	451,075
Rest		2,800,463		3,595,602		2,944,866		2,757,400
Total		14,889,763		14,889,763		14,889,763		14,889,763
Overproduction		5,534,342		0		1,664,798		1,767,961

Red: overproduction

Blue: without overproduction

Conclusions and implications

Mineral production could be restricted by environmental issues.

- In particular, copper could be the most concerned.

=> Improvement of water intensity for production, exploration of substitutes, and establishment of recycling technologies and systems are crucial.

The proposed PB approach can support industries and resource management policy.

- Preparation for future disruption
- Exploration of materials for technology development

Our study featured in Science

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The first ever PB definition of mineral production in the world.

Islam et al. 2025. *Science*, 387(6739), 1214–1218.

SUSTAINABILITY

Geological resource production constrained by regional water availability

Kamrul Islam[1], Keitaro Maeno[1], Ryosuke Yokoi[1], Damien Giurco[2], Shigemi Kagawa[3], Shinsuke Murakami[4], Masaharu Motoshita[1*]

Although the global economy requires geological resource mining, production has substantial environmental impacts, including the use of regional available water. In this study, we shed light on the global production capacity of 32 mined geological resources, considering regional water availability as a constraint. We found that current resource mining greatly exceeds regional water constraints for several, notably copper (37% of current production exceeds available water capacity) in 2010. Changing the location of production to regions of lower water stress would alleviate current exceedances of water constraints; however, considering economic factors shows that this is not always feasible. Future demand for geological resources is expected to require a considerable increase in water consumption. Considering the constraints of water resources in geological resource production is crucial for sustainability.

Mined geological resources, for example, minerals, metals, and rocks, are essential for developing and sustaining the global economy. Since the early 2000s, geological resource extraction has risen by more than 50% (*1*), driven by increasing demand for raw materials, and this upward trend is expected to continue because of the build-up of global material stocks (*2*) and the expansion of low-carbon infrastructures, such as wind and solar energy and battery storage capacities (*3*, *4*). The extraction and processing of geological resources can lead to several adverse environmental effects, including land use changes (*5*–*10*), biodiversity loss (*11*–*13*), increased CO_2 emissions (*14*), acid mine drainage (*15*), periodic tailings dam disasters (*16*), and water pollution (*17*). The significant increase in the production of mined geological resources is a part of the "great acceleration" (*18*) arguably pushing the global socioeconomic metabolism beyond planetary boundaries (*19*, *20*), which defines a safe operating space for the current society to develop and thrive while maintaining the resilience and functioning of the earth system.

Mining and processing operations of geological resources require great amounts of water, often entering the operations from surface and underground water sources (*21*–*23*). Moreover, water use and consumption in geological resource mining and processing is a critical challenge, as it competes with water use in other production systems, such as agriculture. Mining, although constituting a small fraction of global water use (2 to 4.5% in mining-intensive countries), substantially strains regional water supplies, impacting quantity and quality (*24*). Our previous study determines sustainable water use by regional carrying capacities (RCCs), which are defined as the remaining water for humanity after securing water for ecosystems (*25*). According to the estimate based on this approach, fresh water use currently exceeds the limits of water resources at the regional level, depriving aquatic ecosystems of the water they need to endure. Therefore, geological resource production at the location where water is overexploited beyond the carrying capacity will need to reduce production (to the limit for aquatic ecosystem conservation).

In this study, we aimed to determine a sustainable capacity for geological resource production under the constraint of regional available water and identify the potential gaps between sustainable production and projected future demand. Firstly, we established datasets on water consumption intensity for producing 32 geological resources in 2010 (table S1), representing all geological resources available in the SNL database, through an extensive literature review. The SNL database provides the operational data of global mines with the largest coverage, including the mined volume of each geological resource (*26*). Linking water consumption intensity with geological resource production data from the SNL database enabled estimates of the water consumption volume for geological resource production on a global scale. Secondly, we defined the overproduction of geological resources based on the water volume consumed for geological resource production beyond the RCCs of water resources of global watersheds, which were estimated in a previous study (*25*). Thirdly, we explored the theoretical potential of alleviating the overproduction of geological resources based on three defined scenarios. Lastly, we demonstrated how water constraints may cause gaps between sustainable production and projected future demand for geological resources following socioeconomic pathways (SSPs) as future scenarios (see details in materials and methods) (*27*–*29*). The definitions of key terms in this work are available in table S2.

Results

Water consumption for geological resource production and its spatial distribution

The total water consumption for geological resource production [including extraction, crushing, processing, and refining (see details in materials and methods)] in 2010 from the 3319 mines studied was estimated to be 6739 (±1564) million m^3. The estimated volume of water consumption for geological resource production was equivalent to 7 (±2)% of total industrial water consumption in 2010 (96,146 million m^3). Six major geological resources accounted for 94% of the total water consumption for geological resource production in the world: iron (33%), coal (24%), phosphate (15%), copper (10%), gold (8%), and nickel (4%) (Fig. 1; see table S8 for details). Iron and coal required a relatively smaller volume of water consumption per ton produced (table S3), whereas the relatively larger production volumes contribute to the dominant water consumption for these geological resources (table S4). By contrast, phosphate production was less than one-tenth that of iron and coal but resulted in a comparable amount of water consumption for its production because it is so water intensive.

Fig. 1. Breakdown of the total water consumption (million cubic meters) for mineral production by geological resource.

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Questions and comments?

Want to know more/collaborate?

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