Low carbon technologies and critical metals: Revisiting the criticality and implications for scaling up the deployment of low carbon technologies

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Ifri Center for Energy & Climate
Paris, 6 September 2021

Outline

1. **Cobalt, copper, lithium, nickel, platinum group metals, rare earths, graphite, sand: Mapping global production and ressources and the footprint of China**

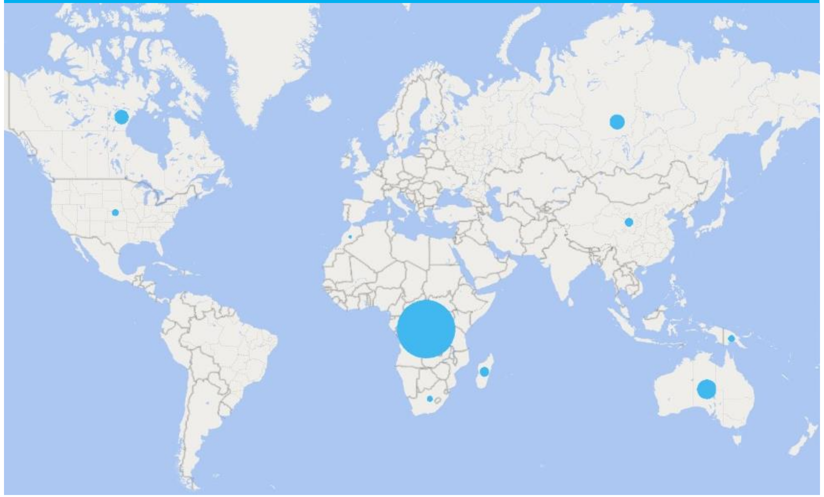
2. The thirst for minerals: the pressure of low carbon technologies on resources and supplies

3. The Ifri criticality index: identifying and measuring the vulnerabilities by sector and resources

Over two thirds of the world's cobalt production comes from the Democratic Republic of Congo (DRC)

Cobalt production – 2020
Share of OECD production: 6.8%

Cobalt reserves
Share of OECD reserves: 9.5%

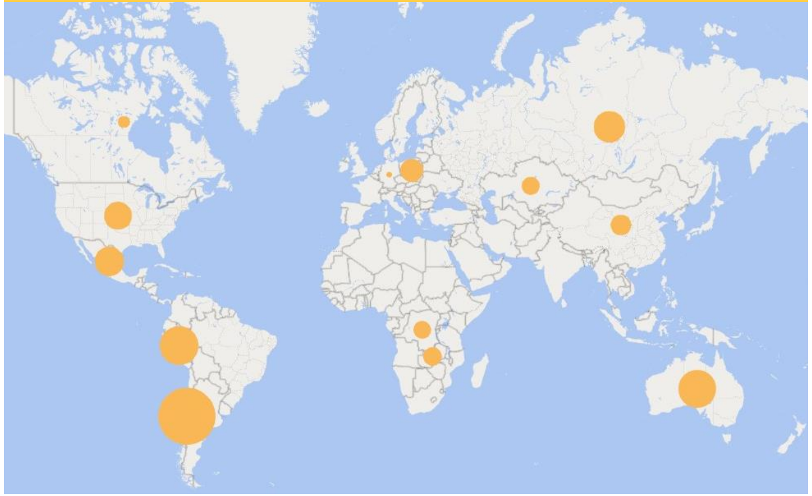


Source: US Geological survey

Copper is produced on all continents even in Europe (Poland), one third comes from Chile

Copper production – 2020
Share of OECD production: 56%

Copper reserves
Share of OECD reserves: ***64%***



Source: US Geological survey

Australia currently accounts for half of the global lithium production, but the largest resources are in Chile

Lithium production – 2020
Share of OECD production: 71%

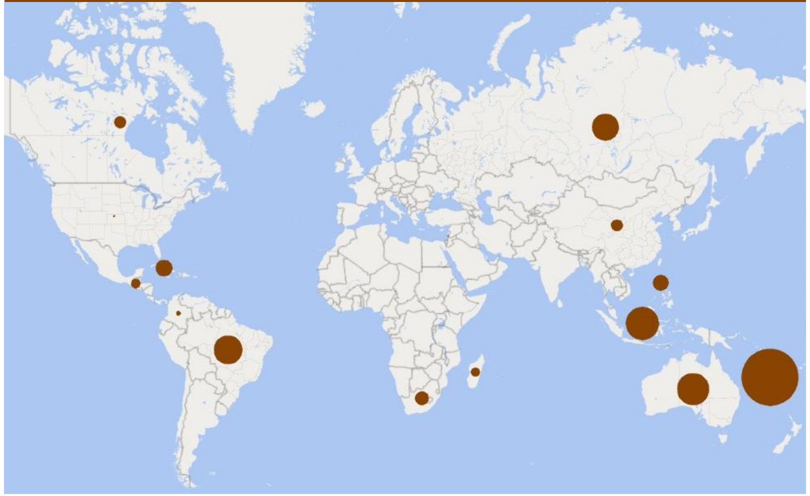
Lithium reserves
Share of OECD reserves: 69%

Source: US Geological survey

High concentration of nickel production and ressources in the Asia Pacific Region, some significant resources also in Brazil

Nickel production – 2020
Share of OECD production: ***16%***

Nickel reserves
Share of OECD reserves: ***23%***



Source: US Geological survey

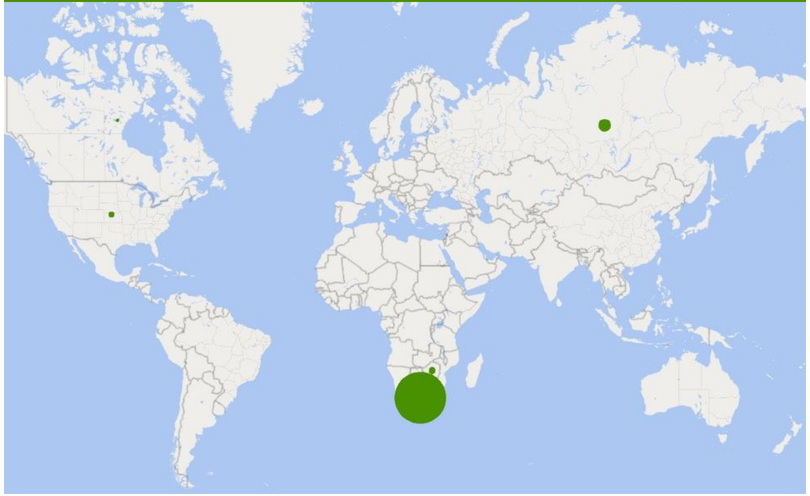
South Africa is and will be leading the production of Platinum group metals*, followed by Russia

Platinum group metals production – 2020

Share of OECD production: 12%

Platinum group metals reserves

Share of OECD reserves: 2%



* The six platinum group metals are ruthenium, rhodium, palladium, osmium, iridium and platinum

Source: US Geological survey

China will remain the leader in rare earths production, the US will take a back seat to Russia, Vietnam, Brazil and India

Rare Earths production – 2020

Share of OECD production: 23%

Rare Earths reserves

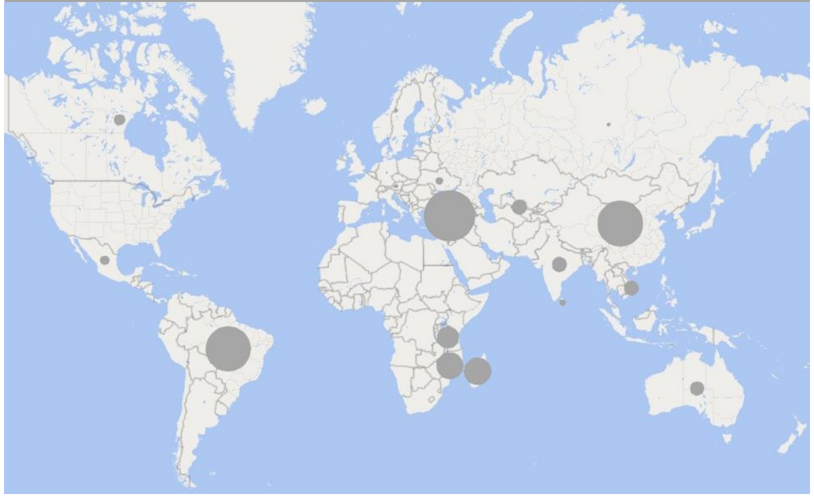
Share of OECD reserves: 7%

Source: US Geological survey

Graphite production, key for anodes / cathodes, is concentrated in China and Brazil, yet China is also number one importer

Graphite production – 2020
Share of OECD production: ***14%***

Graphite reserves
Share of OECD reserves: 29%

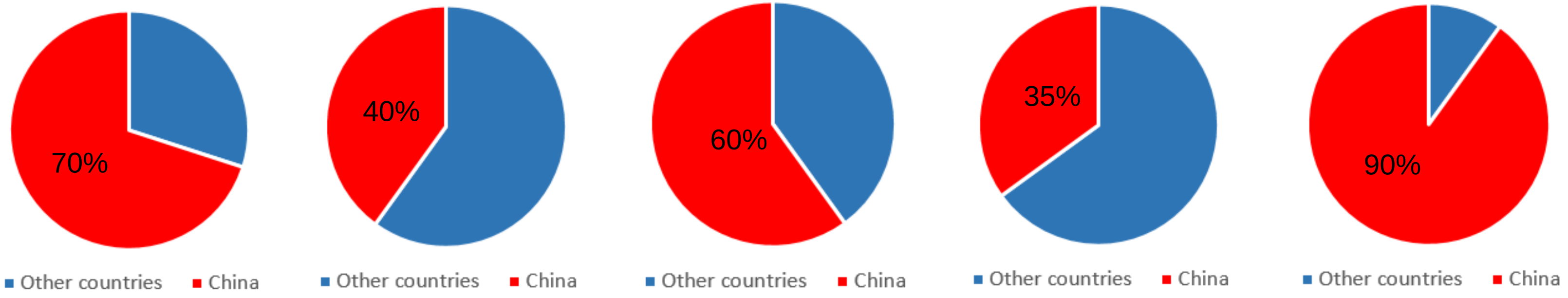


China and Turkey together represent ¾ of resources but Europe has an opportunity to develop natural graphite supplies, notably in Sweden.

Source: US Geological survey

The world relies on China for raw material extraction and refining processes

Chinese market share in metals refinery*



Cobalt	Copper	Lithium	Nickel	Rare Earths

Source: IEA, Ifri estimates

Challenges ahead:

Declining ore quality

→ Refining process will become more energy intensive and more carbon intensive

→ More waste will be produced, hence a need to develop R&D on the use that could be made of by-products & hope to produce less waste

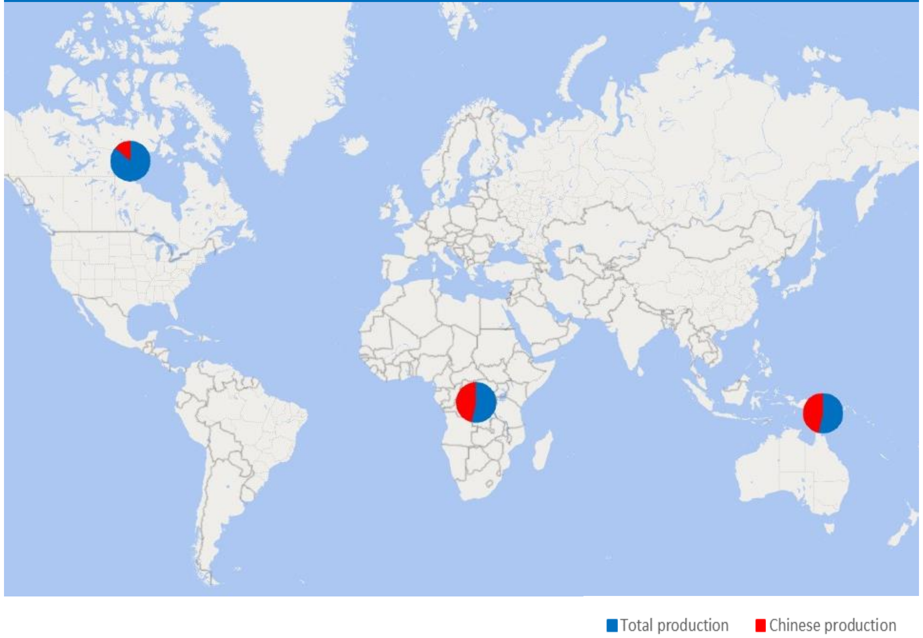
Decarbonising refining processes and ensuring high environmental standards

→ Need for low carbon electricity supply since refining is an electricity-intensive process

→ Since electricity accounts for ¼ of total refining cost, low carbon electricity must be competitive

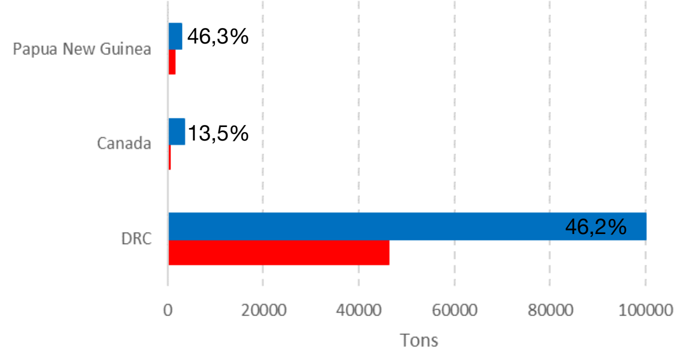
Chinese companies control half the cobalt market in Papua and DRC, and around 15% in Canada

Main geographical location of Chinese cobalt mining and share in total national production



In April 2021, Chinese battery giant CATL acquired a 25% stake in the Kisanfu mine in the DRC, one of the world's largest undeveloped sources of cobalt. The Chinese share of production in the country will therefore further increase significantly.

Share of Chinese cobalt mining

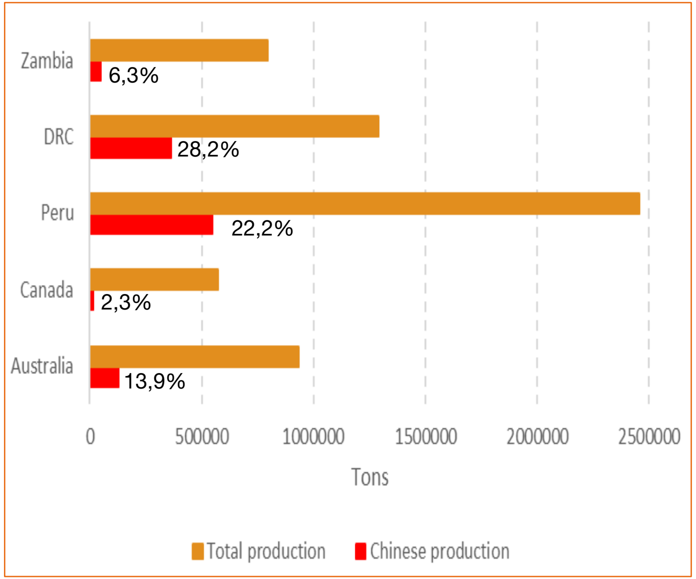


Source: Ifri, based on companies reports

China is the world largest copper importer yet Chinese companies are involved in copper production notably in Peru, DRC

Main geographical location of Chinese copper mining and share in total national production

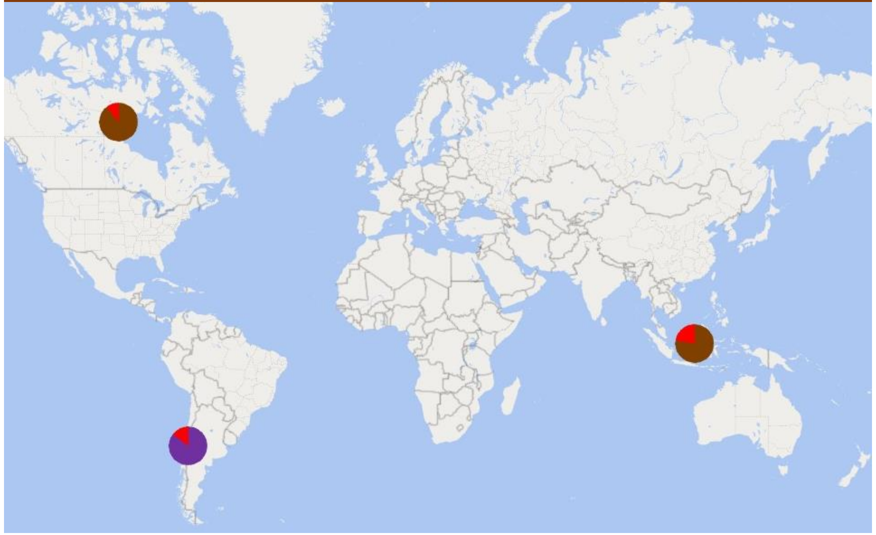
Share of Chinese copper mining



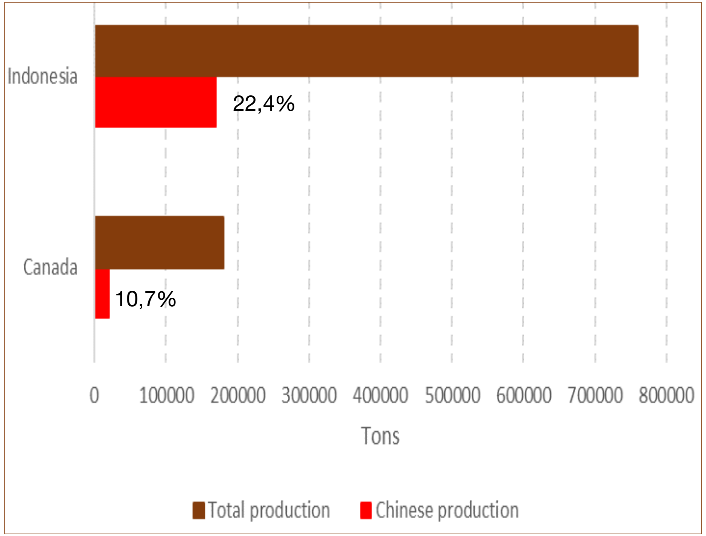
Source: Ifri, based on company reports

China is also influential in nickel and lithium production

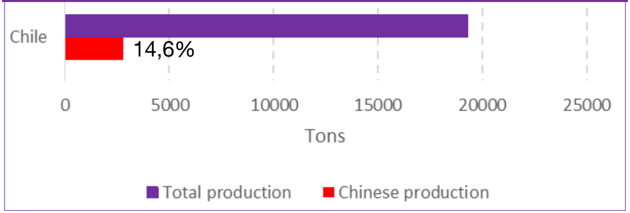
Main geographical location of Chinese nickel & lithium mining and share in total national production



Chinese nickel mining in key countries



Chinese lithium mining in Chile



Source: Ifri, based on company reports

China is the world's leading consumer of lithium, primarily for battery manufacturing. One can therefore expect a rise in Chinese investments & influence, particularly in Chile, even if planned investments have been delayed or cancelled due to the pandemic.

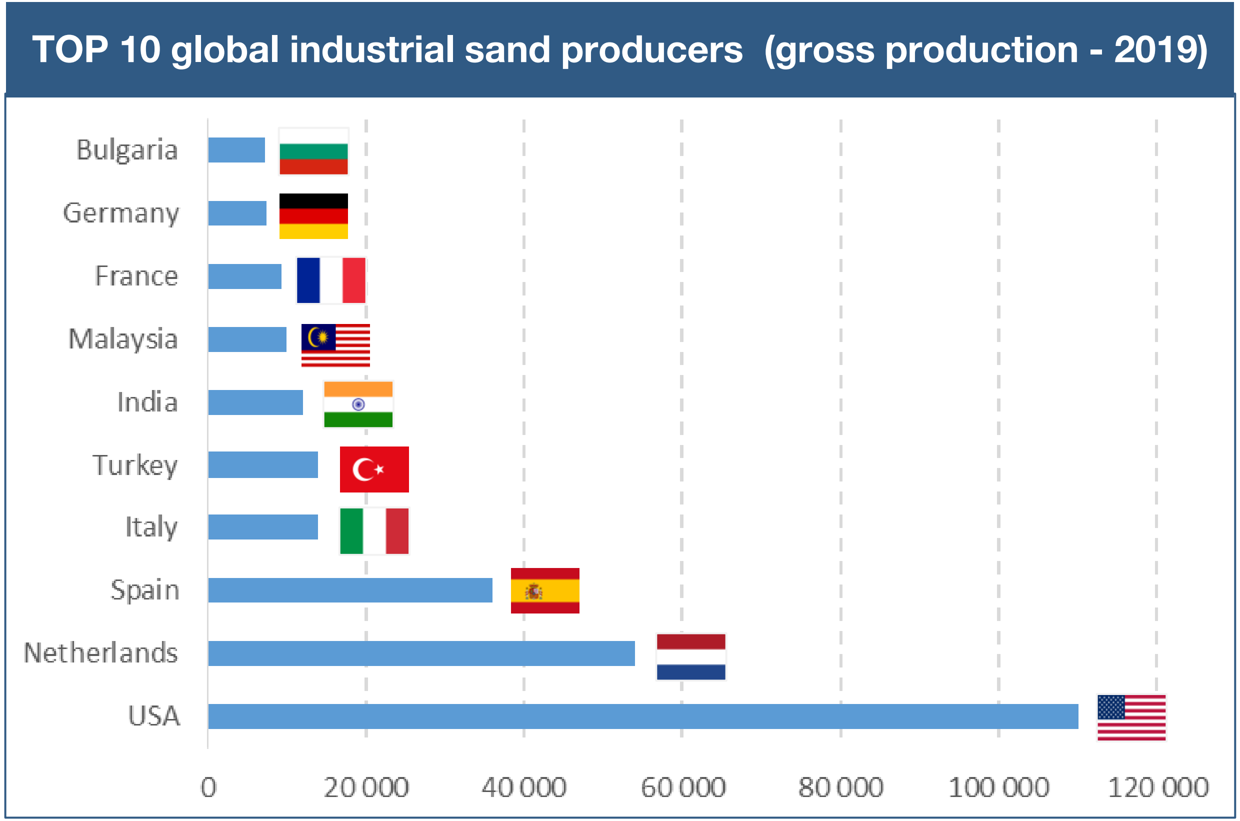
Singapore is the leading sand importer to meet its expansion ambitions, Qatar needs aggregates

TOP 10 global sand exporters & importers (gross value - 2018)											
Sand						Aggregates					
Exporters	Gross value (USD x 10^6)	Share of world total (%)	Importers	Gross value (USD x 10^6)	Share of world total (%)	Exporters	Gross value (USD x 10^6)	Share of world total (%)	Importers	Gross value (USD x 10^6)	Share of world total (%)
USA	363	19	Singapore	176	9.2	UAE	619	26	Qatar	405	17
Germany	166	8.7	Canada	141	7.4	Norway	214	9.0	USA	198	8.3
Netherlands	159	8.3	Belgium	138	7.2	China	190	8.0	Netherlands	186	7.8
Belgium	155	8.1	Netherlands	132	6.9	Germany	171	7.2	Singapore	169	7.1
Australia	134	7	Germany	122	6.4	Belgium	114	4.8	Germnay	124	5.2
Malaysia	120	6.3	China	99	5.2	France	100	4.2	Kuwait	124	5.2
China	61	3.2	Japan	88	4.6	Mexico	74	3.1	Hong Kong	112	4.7
Vietnam	61	3.2	Italy	63	3.3	Canada	71	3	France	102	4.3
France	59	3.1	Mexico	63	3.3	Indonesia	76	3.2	Switzerland	95	4
Saudi Arabia	55	2.9	UAE	55	2.9	UK	67	2.8	Denmark	64	2.7
TOTAL Top 10	**1,333**	**70**	**TOTAL Top 10**	**1,077**	**56**	**TOTAL Top 10**	**1,697**	**71**	**TOTAL Top 10**	**1,578**	**67**
World total	**1,910**	**-**	**World total**	**1,910**	**-**	**World total**	**2,380**	**-**	**World total**	**2,380**	**-**

Source: MIT, 2018 Global Aggregates Information Network

The global aggregate demand could reach 60 billion tonnes per anum by 2030 against current 40-50 billion tonnes, whereas sand availability can hardly be further increased.

The US is by far the largest producer of industrial sand, ahead of European countries that are well positioned though



US Geological survey

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Low carbon technologies: High aluminum demand for wind power, H2 electrolyser technology very copper intensive

	Onshore wind	Offshore wind	Hydrogen	
Mineral intensity (t/GW)	Aluminium: 600 (500 - 700) Copper: 4000 (3000 - 5000) Nickel: 290 (240 - 340) Dysprosium: 11.5 (6 - 17) Neodymium: 104 (28 - 180) Praseodymium: 22 (9 - 35)	Aluminium: 1500 (1400 - 1600) Copper: 1125 (950 - 1400) Nickel: 435 (430 - 440) Dysprosium: 4 (2 - 6) Neodymium: 31.5 (12 - 51) Praseodymium: 2 (0 - 4)	*PEM electrolysis*	Platinum: 0.3 Iridium: 0.7 *Total PGM*: 1
			HT electrolysis	Yttrium: 5.2
			Alkaline electrolysis	Nickel: 44.5 Copper: 125
Water consumption (gallons/MWh)	15	25	39.5 (16 - 63)	
Demand for concrete (t/MW)	296 (243 - 349)	384 (355 - 413)	-	
GHG emissions (gCO2 eq/kWh)	12.1 (9.2-14.5)	14.1 (10.8 – 16.4)	31 (2.5 - 30)	

Source: See Annex

Nuclear power requires significant water consumption, CSP is the most carbon intensive renewable energy

	Nuclear	Solar PV	Concentrated solar power
Mineral intensity (t/GW)	Aluminium : 1077 (709 - 1446) Copper: 2503 (1864 - 3142) Nickel: 1250 (1200-1300)	Aluminium: 6750 (6000 - 7500) Copper: 4150 (3700 - 4600)	Aluminium: 5500 (0 - 11000) Copper: 2300 (1400 - 3200) Molybdenum: 128 (56-200) Nickel: 1370 (940 - 1800)
Water consumption (gallons/MWh)	560 (400 - 720)	23 (20 - 26)	52.9 (32.5 - 73.2)
Demand for concrete (t/MW)	284 (183 - 385)	54.6 (48.6 - 60.7)	161 (72 - 250)
GHG emissions (gCO2 eq/kWh)	42.5 (25 - 60)	30 (14 – 61)	37.4 (28.8 - 45.9)

Source: See Annex

Ubiquity of copper and nickel in low-carbon technologies, Rare Earth Elements needed for wind techs

	Onshore wind	Offshore wind	Hydrogen (electrolysis)	Nuclear	Solar PV (CIGS)	Concentrated solar power
Copper *Demand (t/GW)*	**X** *4 000*	**X** *1125*	**X** *125*	**X** *2503*	**X** *4150*	**X** *2 300*
Nickel *Demand (t/GW)*	**X** *290*	**X** *435*	**X** *44.5*	**X** *1250*		**X** *1 370*
Rare Earth Elements *Demand (t/GW)*	**X** *137.5*	**X** *37.5*	**X** *5.2*			
Platinum Group Metals *Demand (t/GW)*			**X** *1*			

Wind turbines & solar farms with their networks use more than 10 times as much of copper as non-renewable energy systems

Source: See Annex

5G, smartphones and EVs have also a strong impact on demand for critical metals

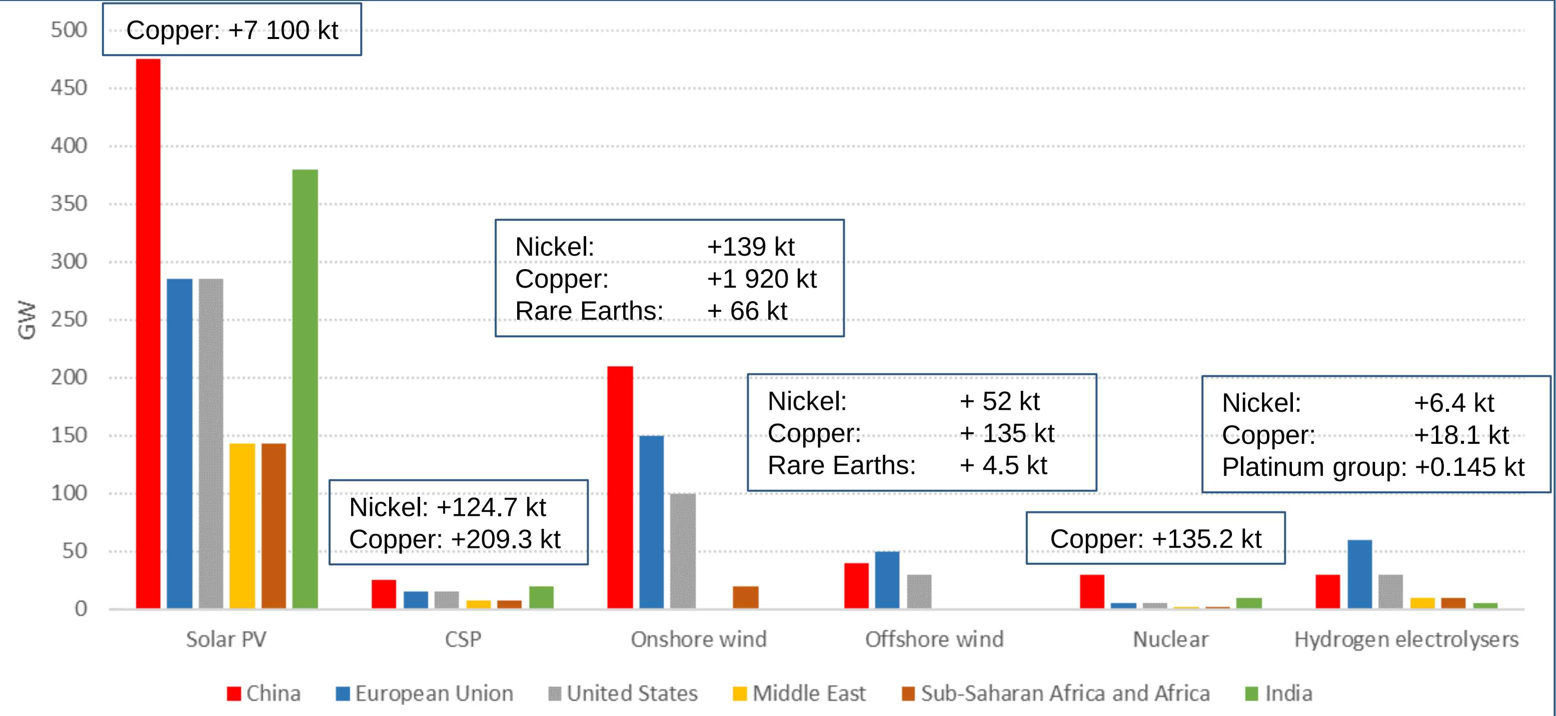
	5G	Smartphones & Laptops	Electric Vehicles
Cobalt	X *(antennes)*	X *(battery)*	X *(battery)*
Copper	X *(base stations)*	X *(printed circuit boards)*	X *(charging stations)*
Lithium		X *(battery)*	X *(battery)*
Nickel		X *(battery)*	X *(battery)*
Rare Earth Elements		X *(magnets & printed circuit boards)*	X *(permanent magnet - motor)*
Platinum Group Metals		X *(contact surfaces)*	

An electric car contains between 2 and 4 times more copper than a conventional car (up to 80 kg). 5G will be a major source of cobalt demand: cobalt demand for portable devices could rise by 60% in the next 5 years.

Source: See Annex

Solar PV will constitute the bulk of added capacities in leading markets by 2030, followed by onshore wind

Capacity additions by 2030 of key low carbon technologies by selected regions/countries and respective additional demand on selected metals



Source: IEA, Irena, Ifri estimates

Demand for platinums and copper will soar, hydrogen and onshore wind will drive nickel demand

Total metals demand for capacity additions of low carbon technologies by 2030 in the selected regions/countries								
	Onshore	Offshore	Hydrogen	Nuclear	PV	CSP	TOTAL	% of 2019 global production
Nickel	139 200	52 200	6 452	0	0	123 300	**606 070**	**12%**
Copper	1 920 000	135 000	18 125	135 162	7 096 500	207 000	**10 528 562**	**47%**
Platinum Group Metals	0	0	145	0	0	0	**188.5**	**69%**
Rare Earth Elements	66 000	4 500	0	0	0	0	**70 500**	**32%**

Copper will largely be used for PV panels and rare earths to set up onshore wind turbines. Given that platinum is (for now) mainly consumed by the automotive sector (exhaust treatment systems mostly) and jewelry, conflicts between industries – such as with hydrogen are more than likely.

China and the EU will concentrate the bulk of the world's incremental metal demand, followed by the US

Total metals demand for capacity additions by 2030 in selected regions/countries

	China	European Union	USA	Middle East	Sub-Saharan Africa and Africa	India
Nickel	113 885 (4%)*	88 470 (3.5%)	63 935 (2.5%)	10 720 (0.5%)	16 520 (0.6%)	27 622 (1%)
Copper	2 992 590 (15%)	1 893 515 (9%)	1 667 265 (8%)	614 881 (3%)	694 881 (3.5%)	1 648 655 (8%)
Platinum Group Metals	30 (14%)	60 (28%)	30 (14%)	10 (5%)	10 (5%)	5 (2.4%)
Rare Earth Elements	30 375 (14%)	22 500 (10%)	14 875 (7%)	0	2 750 (1.3%)	0

** Percentage of 2019 global production*

The demand for platinum group metals (only for energy transition technologies) from these areas and countries will account for more than 2/3 of the 2019 production

By 2030, the world needs 5 times more lithium, 3 times more cobalt, 1.5 to 3 times more REE, PGM and copper

	2019 production (Tons, thousands)	2030 projected annual demand (Tons, thousands)	2030 projected annual demand as a percent of 2019 annual production	Trends in production between 2009 and 2019
Cobalt	144	250 - 440	**174 - 305%**	+161%
Copper	20 400	40 000 - 50 000	**196 - 246%**	+ 128%
Lithium	86	260 - 475	**302 - 552%**	+ 306%
Nickel	2 610	2 500 - 3 500	**96 - 134%**	+ 164%
Rare Earth Eléments (REE)	220	280	**127%**	+ 165%
Platinum Group Metals (PGM)	0.210	0.320 - 0.480	**152 – 228%**	+ 109%

Source: See Annex

Supply tensions by 2030 very likely for copper & cobalt, to a lesser extent platinum, while the risk is moderate for lithium

Assessment of 2030 possible supply tensions from several metals and elements, solely based on supply and demand trends

	LEVEL OF POSSIBLE SUPPLY TENSION
Cobalt	
Copper	
Platinum Group Metals (PGM)	
Lithium	
Nickel	
Rare Earth Elements	

High

Low

Overview of the role of OECD countries in the raw material extractive industry

	SHARE OF OECD COUNTRIES PRODUCTION	*SHARE OF OECD COUNTRIES RESERVES*
Cobalt	7%	9.5%
Copper	56%	64%
Lithium	71%	69%
Nickel	16%	23%
Platinum group metals	12%	2%
Rare Earths	23%	7%
Graphite	14%	29%

Source: Ifri calculations, based on US Geological survey, BRGM data

By projecting 2030 demand and estimating production in 2030 based on current production levels and available reserves, a quantitative estimate reveals that serious tensions can be expected for cobalt, copper and PGM. Yet the situation can get also critical for nickel and rare earths, when including the geopolitics, environmental and social aspects.

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Ifri’s criticality index for metals: explanations

❑ Exposure to political issues

This index takes into account the level of stability of each country, production volumes, level of corruption, regulatory quality, rule of law indicators, top companies and their status (state-owned or not). An important weight is given to state control on companies.

❑ Exposure to water-related issues

This index takes into account the water stress indicator of each country, the type of resources extracted and their water footprints, and production volumes.

❑ Exposure to social issues

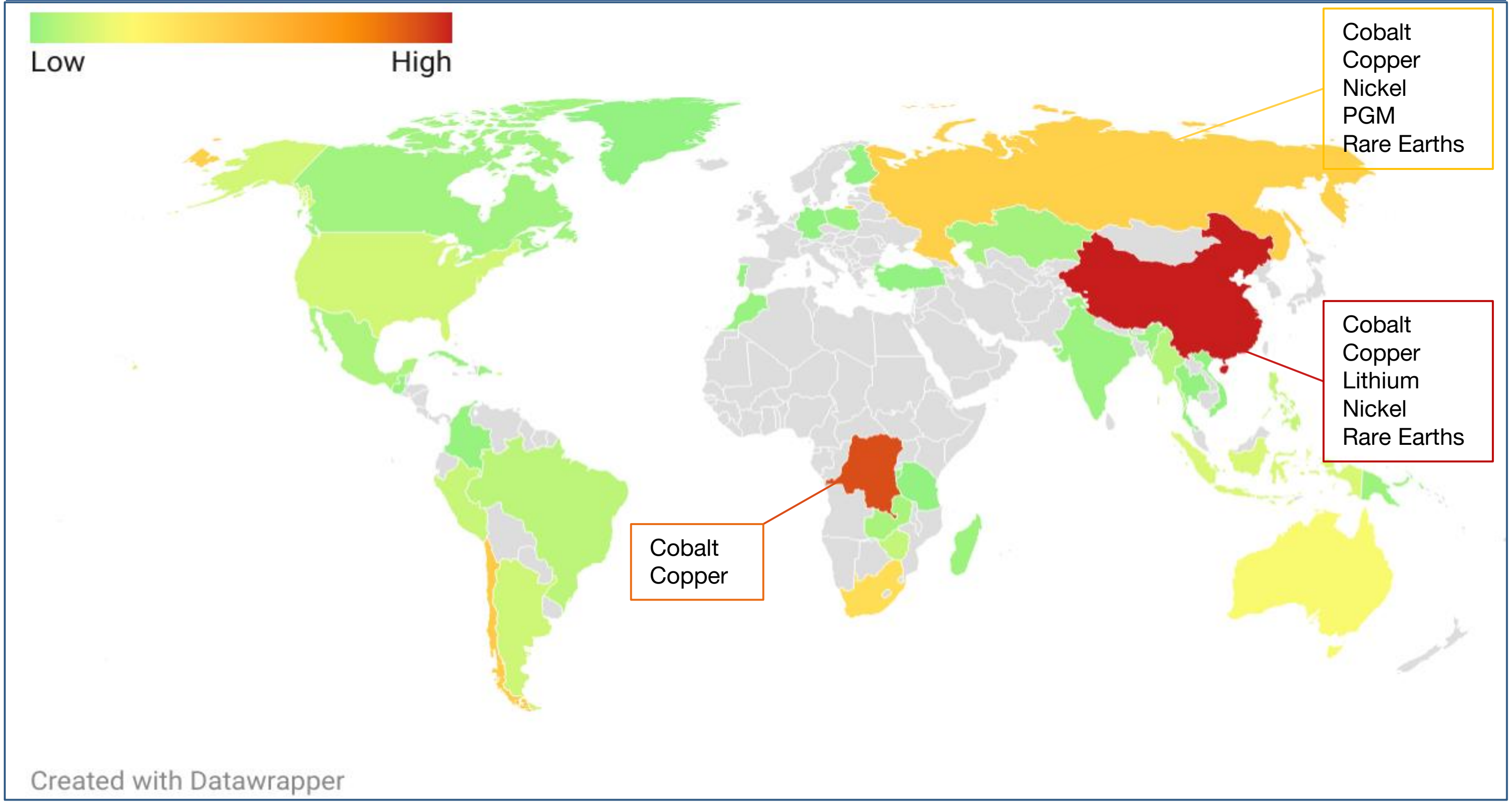
This index takes into account the social coverage of workers, child labor, vulnerability to slavery, and production volumes.

❑ Exposure to environmental issues

This index takes into account the type of resources extracted and their carbon footprint, impact on biodiversity, waste, water pollution, recycling quality and production volumes.

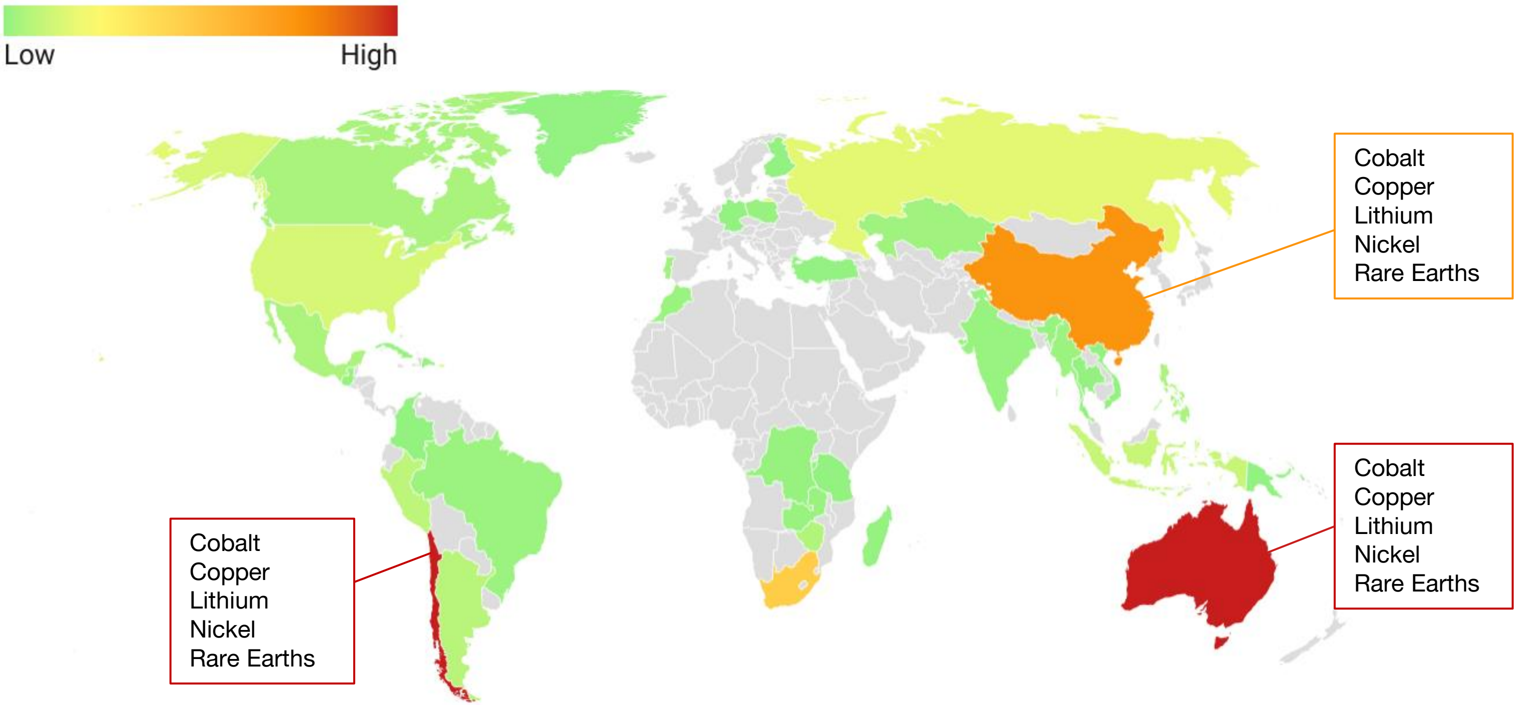
China and DRC pose very significant political risks, Russia and South Africa also, to a lesser degree

Levels of exposure to political risks in leading producing countries (volume-weighted)



Water resources may be a limiting factor for mining production in Australia and Chile, vigilance also in China and South Africa

Levels of exposure to water-related issues in leading producing countries (volume weighted)



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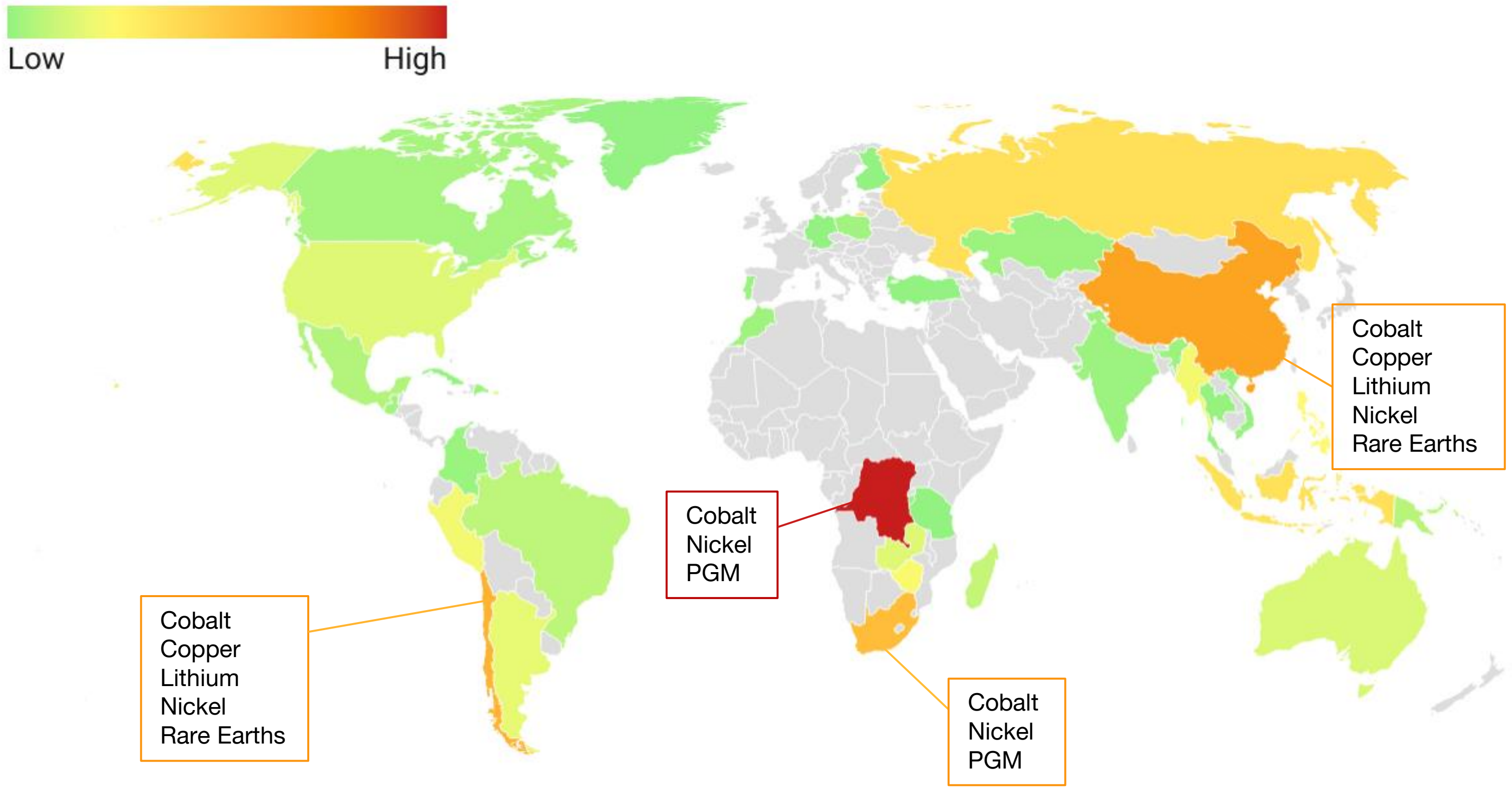
Major social issues in the DRC, South Africa, Russia and Chile could affect supplies

Levels of exposure to social issues in leading producing countries (volume-weighted)



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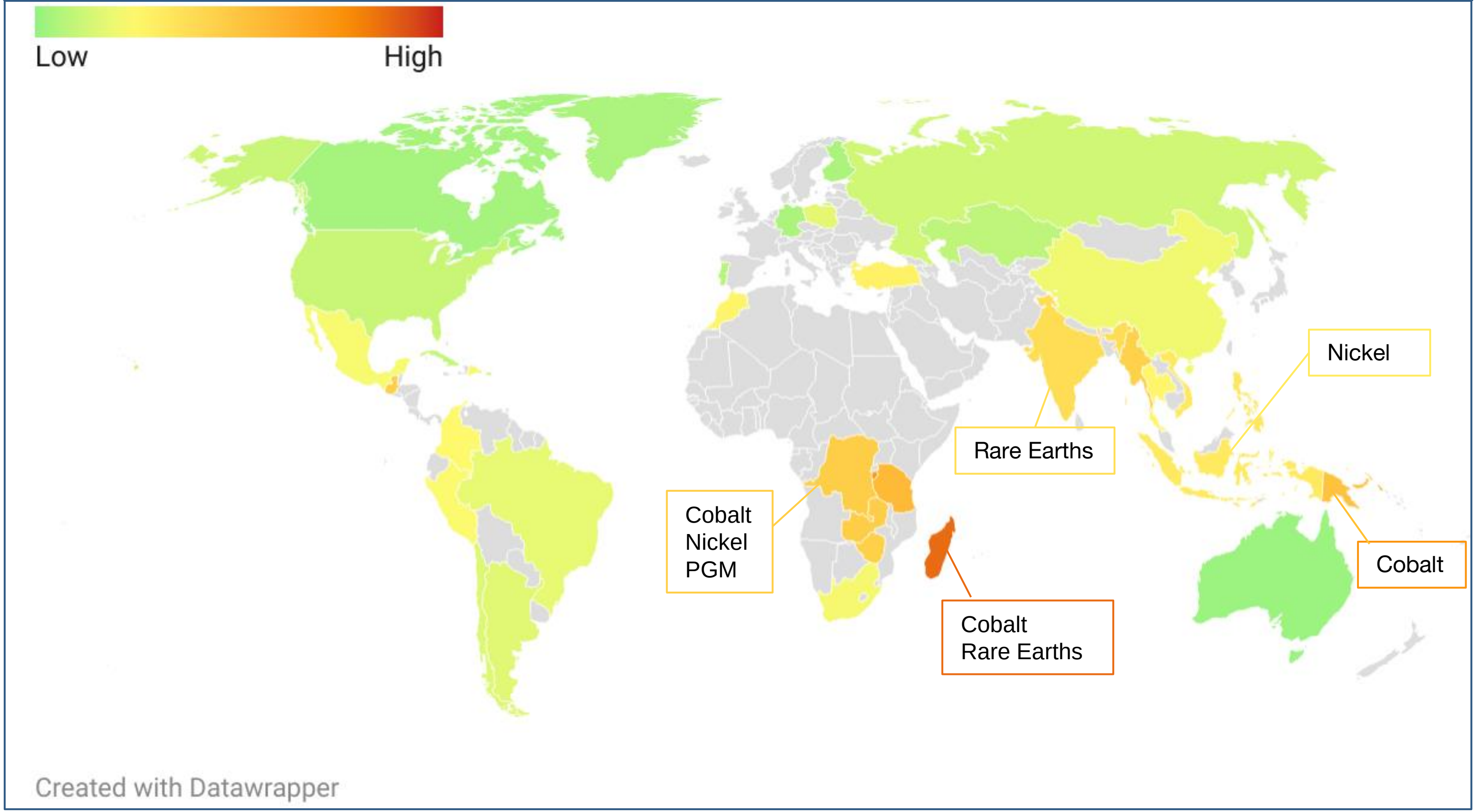
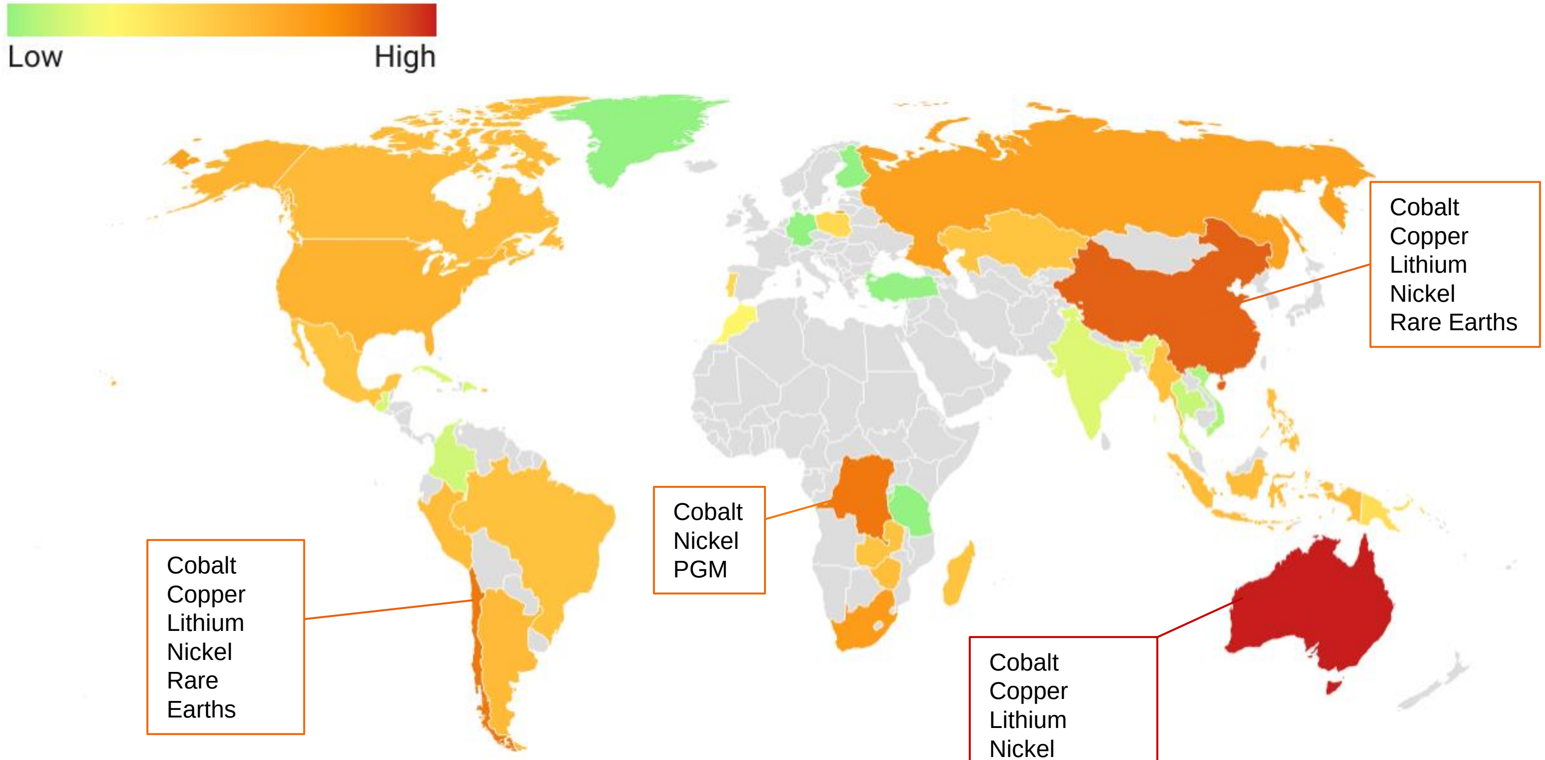
Without taking into account production volumes, African and South Asian producers concentrate the social challenges

Levels of exposure to social issues in leading producing countries (non volume-weighted)



Most producing countries face varying degrees of exposure to environmental degradations

Levels of exposure to environmental issues in leading producing countries (volume-weighted)



Source: Water Resources Institute

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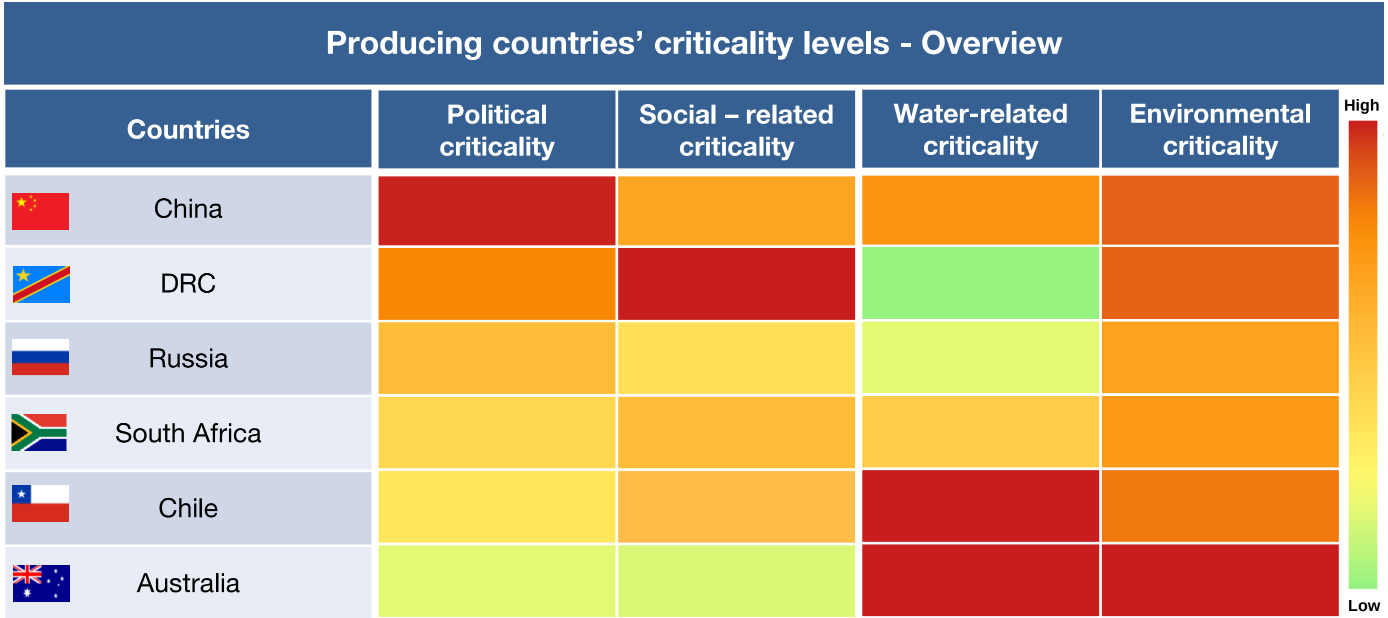
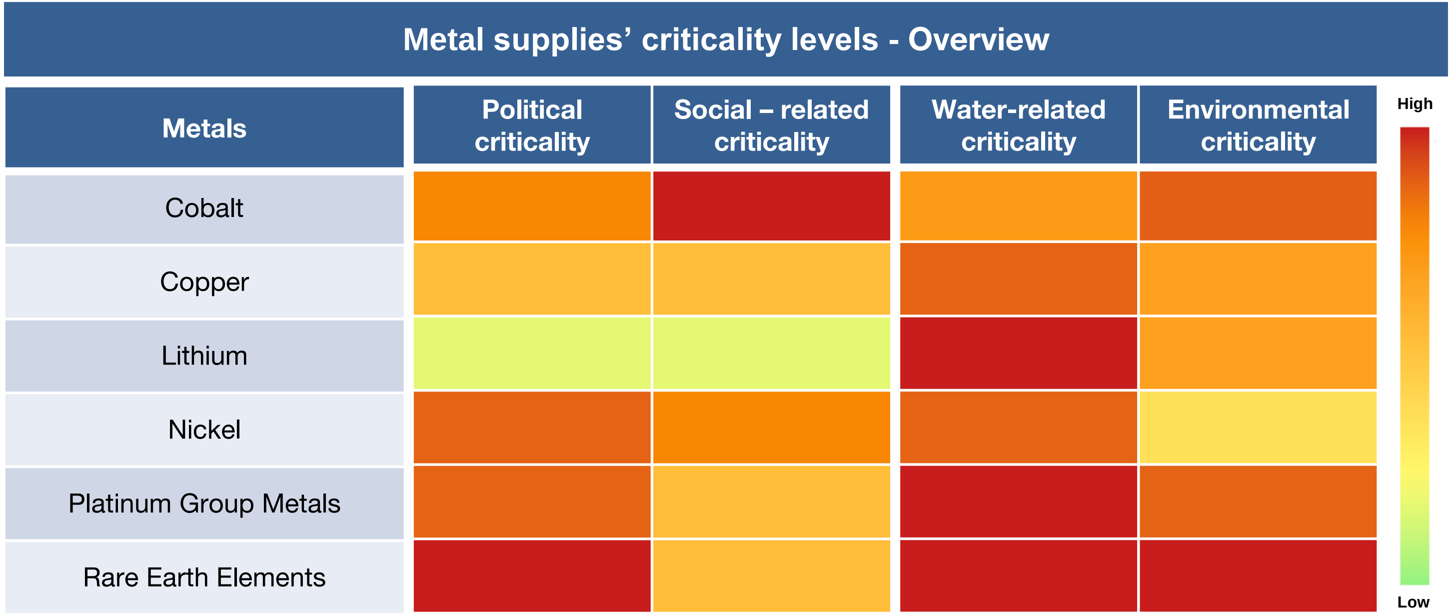
The index highlights that most producing countries feature significant, if not severe, criticality challenges



Given that the Australian water scarcity index could increase by 30% by 2030, and even by 40% in China, water-related levels of criticality could increase dangerously further.

Metals criticality levels are overall high yet rare earths are the most critical, while lithium is relatively the least



The environmental and water criticality levels are highly dependent on technological progress that could be made, like in Chile which may become the first 'green copper' producer using renewable energy sources. Moreover, some low water extraction and processing techniques could be introduced for several metals, with innovation underway.

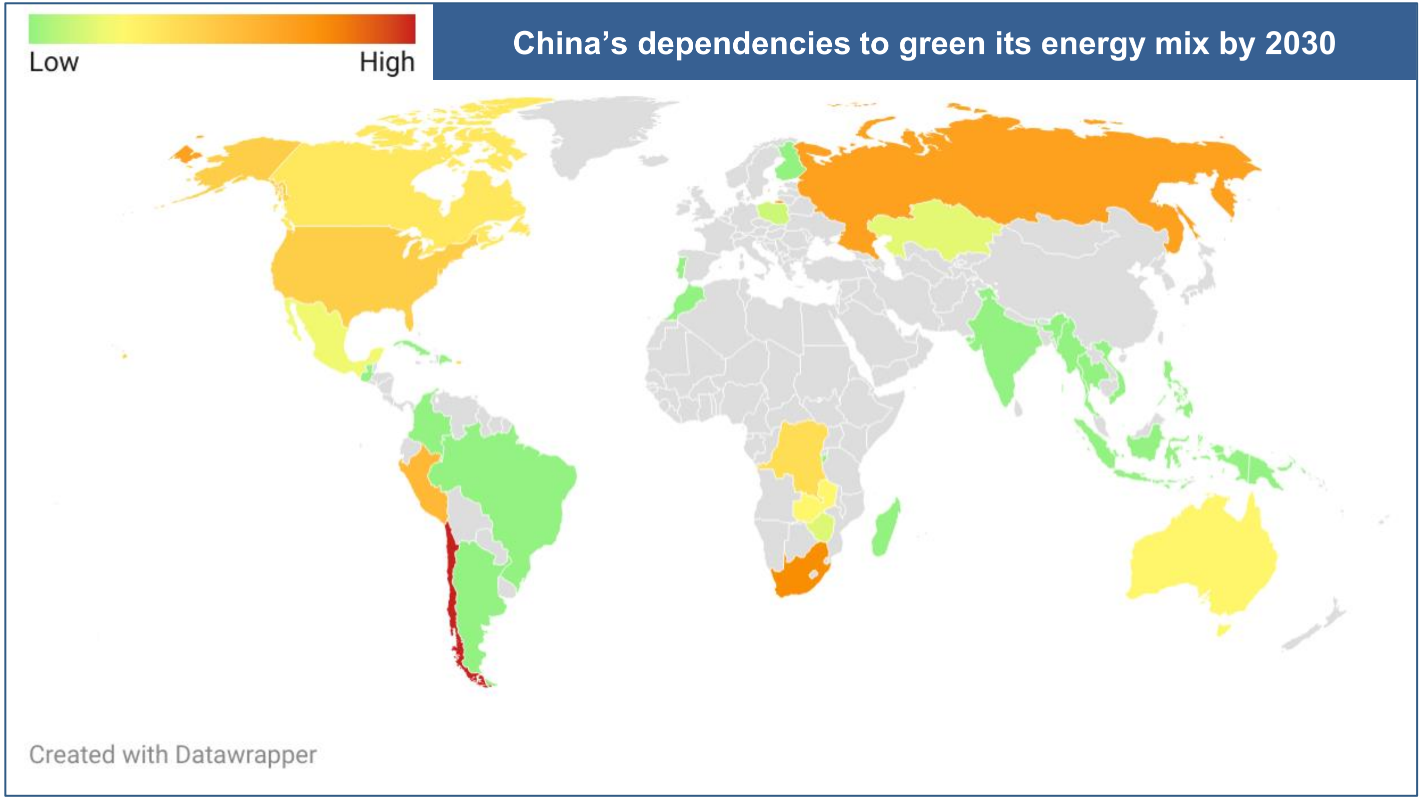
Despite low environmental standards and a real threat to water resources, Chile exports copper around the world

Copper flows, Chilean exports, 2019

Source: UN Comtrade data

Created with Magrit online project, CNRS

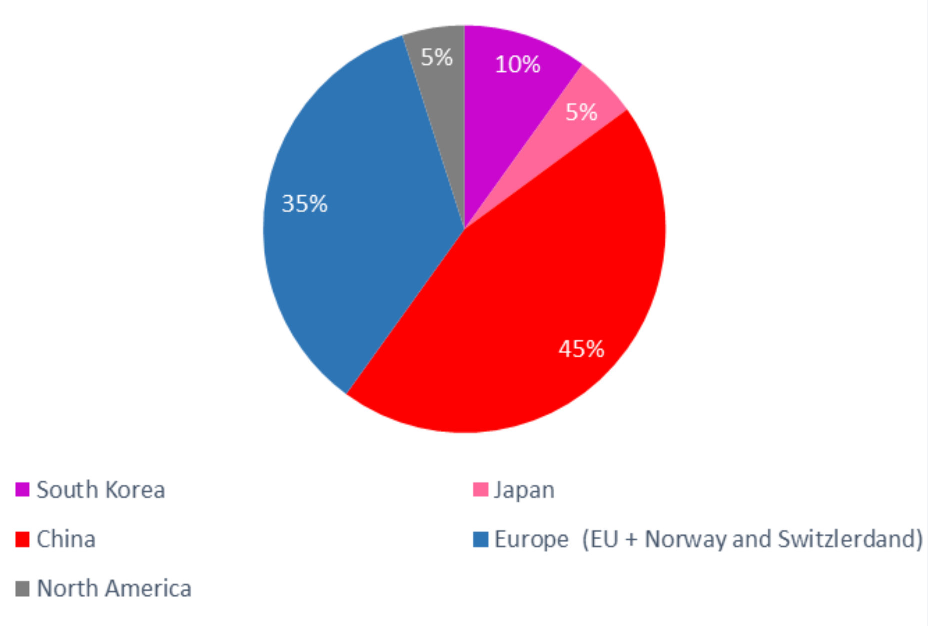
China focuses on solar & onshore wind deployment, increasing its demand for copper and thus relying heavily on Chile



Even if all recycled metals were dedicated to energy technologies, only a fraction of future needs would be covered

- Global recycling factors of critical minerals and metals is very low, between 3-9% in general. Regulation & collection processes are not in place and this is often not economically viable.
- By 2040, total minerals & metals recycling could cover more than 10% of global raw material demand.
- The issue of recycling will become a major strategic issue as China has already taken a significant lead in this area.

Distribution of lithium-ion battery recycling capacities in the world by 2021



Source: IEA, SDS scenario

Sources

Tables on slides 17 to 19

Water consumption:

Onshore wind:
Life Cycle Assessment
Vestas (2018)
Assessment of sustainability indicators for renewable energy technologies
Evans et al. (2009)
Ifri estimate

Offshore wind and PV
Ifri Estimate

CSP
Life Cycle Assessment of a HYSOL Concentrated Solar Power Plant: Analyzing the Effect of Geographic Location
Blanca Corona et al.

Nuclear
Nuclear Energy Institute

Hydrogen
Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies
Andi Mehmeti et al.

GHG emissions:

Onshore and offshore wind, PV
Green Energy Choices: the benefits, risks and trade-offs of low-carbon technologies for electricity production
International Resource Panel, United Nations Environment Program (UNEP)

Nuclear
Life Cycle Greenhouse Gas Emissions from Electricity Generation
NREL

CSP
Life Cycle Assessment of a HYSOL Concentrated Solar Power Plant: Analyzing the Effect of Geographic Location
Blanca Corona et al.

Hydrogen
Ifri estimate

Demand for concrete:

Onshore / offshore wind, PV:
Raw materials demand for wind and solar PV technologies in the transition towards a decarbonized energy system
European Commission
Metal And Concrete Inputs For Several Nuclear Power Plants
F. Peterson et al.

Nuclear
Life Cycle Assessment of the New Generation GT-MHR Nuclear Power Plant
Koltun et al. (2018)

CSP
Material constraints for concentrating solar thermal power
Erik Pihl et al.(2012)

Mineral intensity:

Onshore / offshore wind, PV :
Raw materials demand for wind and solar PV technologies in the transition towards a decarbonized energy system
European Commission

CSP
Material constraints for concentrating solar thermal power
Erik Pihl et al.(2012)

Hydrogen
Life cycle assessment of an alkaline fuel cell CHP system
Staffell et al.
Critical materials for water electrolysers at the example of the energy transition in Germany
Kiemel et al.
Site-Dependent Environmental Impacts of Industrial Hydrogen Production by Alkaline Water Electrolysis
Koj et al.

Nuclear
Life Cycle Assessment of the New Generation GT-MHR Nuclear Power Plant
Koltun et al. (2018)

Sources

Table on slide 20:

Metallic resources in smartphones
B.Bookhagen, et al.
"Cobalt demand for 5G technology to challenge electric vehicles"
Reuters, 2020, September 21th

Table on slide 21:

Cobalt: supply and demand balances in the transition to electric mobility
Joint Research Center
Estimating global copper demand until 2100 with regression and stock dynamics
Branco W.Schipper et al. (2018)
Perspectives on Cobalt Supply through 2030 in the Face of Changing Demand
Environmental Science & Technology, Xinkai Fu et al. (2020)
Major metals demand, supply, and environmental impacts to 2100: A critical review
Takuma Watari et al. (2021)
Assessing Economic Modulation of Future Critical Materials Use: The Case of Automotive-Related Platinum Group Metals
Jingshu Zhang
Scenarios of rare earth elements demand driven by automotive electrification in China: 2018–2030
Xiang-Yang Li

Histogram 'capacity additions' slide 23 :

IEA, European Commission, Energy Information Administration, Ifri estimates

Data used to determine criticality levels

Environmental criticality:

Minerals for Climate Action The Mineral Intensity of the Clean Energy Transition
World Bank
Life Cycle Impact of Rare Earth Elements
ISRN Metallurgy
The environmental profile of platinum group metals (pgms)
The International Platinum Group Metals Association
Life cycle assessment of cobalt extraction process
Shahjadi Hisan Farjana et al.
A Review of the Carbon Footprint of Cu and Zn Production from Primary and Secondary Sources
Anna Ekman Nilsson et al.
The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries
Saeed Rahimpour Golroudbary et al.
Nickel metal life cycle data
Nickel Institute
Scenarios for Demand Growth of Metals in Electricity Generation Technologies, Cars, and Electronic Appliances
Deetman et al. (March 2018)
Various CSR reports

Water-related criticality:

USGS (Minerals production)
Water scarcity Index, World Resources Institute
Life Cycle Assessment
Vestas (2018)
Assessment of sustainability indicators for renewable energy technologies
Evans et al. (2009)
Life Cycle Assessment of a HYSOL Concentrated Solar Power Plant: Analyzing the Effect of Geographic Location
Blanca Corona et al.
Nuclear Energy Institute
Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies
Andi Mehmeti et al.

Social criticality:

Social protection: ILO + World Bank
Child Labour: Save the Children NGO
Slavery: Global slavery Index 2018, Walk Free Fondation

Political critcality:

USGS (Minerals production)
World governance Indicators, World Bank
Various CSR annual reports

Cobalt: supply and demand balances in the transition to electric mobility
Joint Research Center
Estimating global copper demand until 2100 with regression and stock dynamics
Branco W.Schipper et al. (2018)
Perspectives on Cobalt Supply through 2030 in the Face of Changing Demand
Environmental Science & Technology, Xinkai Fu et al. (2020)
Major metals demand, supply, and environmental impacts to 2100: A critical review
Takuma Watari et al. (2021)
Assessing Economic Modulation of Future Critical Materials Use: The Case of Automotive-Related Platinum Group Metals
Jingshu Zhang
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