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

Marc-Antoine Eyl-Mazzega, Juliette Blais
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 resources 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 resources 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

* 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

Source: US Geological survey
Graphite production, key for anodes / cathodes, is concentrated in China and Brazil, yet China is also number one importer.

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**: 70% (China), 30% (Other countries)
- **Copper**: 40% (Other countries), 60% (China)
- **Lithium**: 60% (Other countries), 40% (China)
- **Nickel**: 35% (Other countries), 65% (China)
- **Rare Earths**: 90% (China)

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**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

*Source: IEA, Ifri estimates*
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

- Papua New Guinea: 46.3%
- Canada: 13.5%
- DRC: 46.2%

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

Source: Ifri, based on company reports
China is also influential in nickel and lithium production

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.

Source: Ifri, based on company reports
Singapore is the leading sand importer to meet its expansion ambitions, Qatar needs aggregates.

The global aggregate demand could reach 60 billion tonnes per annum 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.
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3. The Ifri criticality index: identifying and measuring the vulnerabilities by sector and resources
Low carbon technologies: High aluminum demand for wind power, H2 electrolyser technology very copper intensive

<table>
<thead>
<tr>
<th>Mineral intensity (t/GW)</th>
<th>Onshore wind</th>
<th>Offshore wind</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption (gallons/MWh)</td>
<td>15</td>
<td>25</td>
<td>39.5 (16 - 63)</td>
</tr>
<tr>
<td>Demand for concrete (t/MW)</td>
<td>296 (243 - 349)</td>
<td>384 (355 - 413)</td>
<td>-</td>
</tr>
<tr>
<td>GHG emissions (gCO2 eq/kWh)</td>
<td>12.1 (9.2-14.5)</td>
<td>14.1 (10.8 – 16.4)</td>
<td>31 (2.5 - 30)</td>
</tr>
</tbody>
</table>

Source: See Annex
Nuclear power requires significant water consumption, CSP is the most carbon intensive renewable energy

<table>
<thead>
<tr>
<th></th>
<th>Nuclear</th>
<th>Solar PV</th>
<th>Concentrated solar power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption (gallons/MWh)</td>
<td>560 (400 - 720)</td>
<td>23 (20 - 26)</td>
<td>52.9 (32.5 - 73.2)</td>
</tr>
<tr>
<td>Demand for concrete (t/MW)</td>
<td>284 (183 - 385)</td>
<td>54.6 (48.6 - 60.7)</td>
<td>161 (72 - 250)</td>
</tr>
<tr>
<td>GHG emissions (gCO2 eq/kWh)</td>
<td>42.5 (25 - 60)</td>
<td>30 (14 – 61)</td>
<td>37.4 (28.8 - 45.9)</td>
</tr>
</tbody>
</table>

Source: See Annex
### Ubiquity of copper and nickel in low-carbon technologies, Rare Earth Elements needed for wind techs

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

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

<table>
<thead>
<tr>
<th></th>
<th>5G</th>
<th>Smartphones &amp; Laptops</th>
<th>Electric Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>X (antennes)</td>
<td>X (battery)</td>
<td>X (battery)</td>
</tr>
<tr>
<td>Copper</td>
<td>X (base stations)</td>
<td>X (printed circuit boards)</td>
<td>X (charging stations)</td>
</tr>
<tr>
<td>Lithium</td>
<td>X (battery)</td>
<td></td>
<td>X (battery)</td>
</tr>
<tr>
<td>Nickel</td>
<td>X (battery)</td>
<td></td>
<td>X (battery)</td>
</tr>
<tr>
<td>Rare Earth Elements</td>
<td>X (magnets &amp; printed circuit boards)</td>
<td>X (permanent magnet - motor)</td>
<td></td>
</tr>
<tr>
<td>Platinum Group Metals</td>
<td>X (contact surfaces)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- **Nickel:**
  - +139 kt
- **Copper:**
  - +1,920 kt
- **Rare Earths:**
  - +66 kt

- **Nickel:**
  - +52 kt
- **Copper:**
  - +135 kt
- **Rare Earths:**
  - +4.5 kt

- **Copper:**
  - +7100 kt
- **Nickel:**
  - +124.7 kt
- **Copper:**
  - +209.3 kt
- **Nickel:**
  - +6.4 kt
- **Copper:**
  - +18.1 kt
- **Platinum group:**
  - +0.145 kt

Source: IEA, Irena, Ifri estimates
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.

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

* 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.

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

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

<table>
<thead>
<tr>
<th></th>
<th>LEVEL OF POSSIBLE SUPPLY TENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>High</td>
</tr>
<tr>
<td>Copper</td>
<td>High</td>
</tr>
<tr>
<td>Platinum Group Metals (PGM)</td>
<td>Medium</td>
</tr>
<tr>
<td>Lithium</td>
<td>Low</td>
</tr>
<tr>
<td>Nickel</td>
<td>Low</td>
</tr>
<tr>
<td>Rare Earth Elements</td>
<td>Low</td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th></th>
<th>SHARE OF OECD COUNTRIES PRODUCTION</th>
<th>SHARE OF OECD COUNTRIES RESERVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>7%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Copper</td>
<td>56%</td>
<td>64%</td>
</tr>
<tr>
<td>Lithium</td>
<td>71%</td>
<td>69%</td>
</tr>
<tr>
<td>Nickel</td>
<td>16%</td>
<td>23%</td>
</tr>
<tr>
<td>Platinum group metals</td>
<td>12%</td>
<td>2%</td>
</tr>
<tr>
<td>Rare Earths</td>
<td>23%</td>
<td>7%</td>
</tr>
<tr>
<td>Graphite</td>
<td>14%</td>
<td>29%</td>
</tr>
</tbody>
</table>

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

1. Cobalt, copper, lithium, nickel, platinum group metals, rare earths, graphite, sand: Mapping global production and resources and the footprint of China
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3. The Ifri criticality index: identifying and measuring the vulnerabilities by sector and resources
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
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)
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)
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.
The index highlights that most producing countries feature significant, if not severe, criticality challenges.

### Producing countries’ criticality levels - Overview

<table>
<thead>
<tr>
<th>Countries</th>
<th>Political criticality</th>
<th>Social – related criticality</th>
<th>Water-related criticality</th>
<th>Environmental criticality</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Metals</th>
<th>Political criticality</th>
<th>Social – related criticality</th>
<th>Water-related criticality</th>
<th>Environmental criticality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Copper</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Lithium</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Nickel</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Platinum Group Metals</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Rare Earth Elements</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

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.

Source: UN Comtrade data
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**

- **South Korea**: 45%
- **Japan**: 35%
- **Europe (EU + Norway and Switzerland)**: 10%
- **China**: 5%
- **North America**: 5%

*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)
Ifr Institute

**Offshore wind and PV**
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**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)

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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**
Ifr Institute

**Demand for concrete:**
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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
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**Hydrogen**
Life cycle assessment of an alkaline fuel cell CHP system
Staffell et al.
Critical materials for water electrolyzers 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)
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**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
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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 Golroudary 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)
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**Social criticality:**

Social protection: ILO + World Bank
Child Labour: Save the Children NGO
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USGS (Minerals production)
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