Energy transition and (critical) raw materials

Is the supply of Critical Raw Materials a barrier for the Energy Transition?

- Sarah A. Gleeson¹, Christof Kusebauch¹, Manuel Baumann², Steffi Formann³, Ingo Hartmann³, Tobias Naegler⁴, Marcel Weil², Petra Zapp⁵ -

sgleeson@gfz-potsdam.de | ¹GFZ Potsdam & FU Berlin, ²KIT, ³DBFZ, ⁴DLR, ⁵FZJ
Challenges of the sustainable future

**Population growth**
- Increase in global population and increased urbanisation

**Climate change**
- Warming climates, extreme weather events, need for carbon neutrality

---

### Population growth

**1950**

- Map showing population distribution in 1950.

### Climate change

**1946-1950**

- Map showing temperature changes from 1946 to 1950.
Future electricity supply needs to be sustainable

**World view**

- Worlds renewable electricity production from solar and wind increased 5 fold over the last 10 years

**German view**

- Germany plans carbon neutrality by 2045.
- At the same time energy consumption will increase due to electrification of transport and heating.
Green technologies require vast amounts of metals

(New) technologies for energy production and energy storage require new resources!

- Larger total amounts of each metal
- Larger variety of critical and strategic metals needed
- Complicated to predict future needs and markets

Data: IEA report “The role of critical minerals in clean energy transition” (2021)
Metal demand for green technologies is not met by recycling

- Metals will still be in use
- Complex recycling at low recycling rates

→ Need for primary resources i.e. mining
How do we calculate how much is available?

**Economic geology 101:**

There are enough metals on earth but at what costs can they be mined.

**Resources:** a concentration of naturally occurring raw material in such form that economic extraction of a commodity may be possible now or at some future time.

**Reserves:** the economically mineable part of resources that incorporate assessment of “modifying factors” such as material dilution and losses during extraction, available mining, processing, and metallurgical technology, and infrastructure, economic, marketing, legal, environmental, social and governmental factors.

**Mine production:**
Grade: average concentration of the element
Tonnage: tonnes of mineralised material in the deposit (above the “cut-off”)
Calculate the metal produced per year in Mtonnes
Demand Scenarios predict bottlenecks

- Demand scenarios show that there is a significant risk of bottlenecks for supply of most metals in near future!
Demand Scenarios predict bottlenecks

Demand scenarios show that there is a significant risk of bottlenecks for supply of most metals in near future!

How to resolve the problem?

- Reduce the demand?
  - Increase efficiency (i.e., energy, material), life time and use of alternatives (e.g., public transport)
  - Technology and material substitutions

- Increase recycling (on the long term)

- Increase mining production, reserves?
  - Find new deposits. Increase production/mining, but at what cost?
  - Develop unconventional resources of metals

Demand estimates for Energy and Transport technologies + current other applications
Where do our metals come?

Copper sourced mainly from “Porphyry” deposits in South America

Copper (world mine production in 2022)

Current mining for Lithium concentrated in South America, China and Australia

Lithium (world mine production in 2021)

data: bgr.de
How do deposits form and how to find them?

- Metal source
- Fluids or magmas to carry metals
- Heat (e.g. magmatism)
- Geological structures to focus flow (stratigraphic layers, faults)
- Trap site
- All controlled by Geodynamics (plate tectonics)

Complex interactions which only occur very rarely certain times and places in Earth’s history
Exploration below the surface becoming more important

Field work

- Mapping
- Drilling
- Sampling

Advanced tools

- Geophysical (to image the subsurface)
- Geochemical (to analyse the composition)

Models

- Geodynamic (100 km scale)
- Deposit formation (local scale)
Environment, social and governance is now a major project risk

Copper sourced mainly from “Porphyry” deposits in South America

- Cu mining causes stress on water, loss of biodiversity and land resources

Current mining for Lithium concentrated in South America, China and Australia

- about 2/3 of German Li is imported from Chile
Putting environmental impacts into life cycle assessments

- Each process has an environmental impact depending on e.g.:
  - Methods and technology
  - Recycling of chemicals
  - Waste and emission treatment
  - Source of energy
  - Mineralogical factors (e.g. radioactive contaminants, ore grade, gangue minerals)

- Some can be minimized, some not.

<table>
<thead>
<tr>
<th>Category</th>
<th>Global warming potential (GWP)</th>
<th>Acidification (AP)</th>
<th>Eutrophication (EP)</th>
<th>Toxicities to Ecosystems and Humans (ETP, HTP)</th>
<th>Particulate matter (PM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaching</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refining</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example: REE production from different deposits

![Graph showing environmental impacts of REE production from different deposits](graphic.png)

after Zapp et al., 2022 / FZJ
Need to develop unconventional resources

Metals from geothermal fluids!

- Fluids in Earth's crust can contain large quantities of metals
- Potential for local supply with Li (± other metals)
- Currently at demonstrator stage

Raw material recovery from biomass resources

- Plants can accumulate metals and become a potential future resource

Process chain of value element recovery

- Plants can accumulate metals and become a potential future resource

Biomass Value Element Content

<table>
<thead>
<tr>
<th>Plant</th>
<th>Li</th>
<th>Si</th>
<th>Ge</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Brassica napus</em></td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td><em>Triticum aestivum subsp. spelta</em></td>
<td>50</td>
<td>40</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Biomass → Pre-treatment → Thermochemical conversion → Post-treatment → Ash product → Recovery of metals

after Formann & Schliermann (2023) EERA Bioenergy 19:12 / DBFZ
Technology and material substitutions

Lithium is one bottleneck (beside Co, Ni, Cu, C, ...) ... but alternatives in sight!

Alternative provision of lithium

High efficient recycling

Recycling/Circular Economy

Geothermal production

Lithium as a by-product

Development and investigation of alternative chemistries

Sodium batteries are most promising and close to industrial application (in Asia)

Sustainability assessment of different batteries

In which sectors Na batteries can replace Li batteries in the near future?

Baumann & Weil et al. (2022) Advanced energy materials, 12 (46) / KIT

Peters, Baumann, Binder, Weil (2022) Sustainable energy & fuels, 6 (2) / KIT
Is the supply of Critical Raw Materials a barrier for the Energy Transition?

No

- In theory, there is enough metal on earth (discounting geopolitics, environmental, social governance issues)
- Alternative resources and technologies, substitutions in development stage but we need these NOW.

Yes

- Green technologies require massive amounts of metals.
  - Demand will exceed current and projected mine production
  - Finding and developing new mines is challenging and takes decades
  - Recycling rates (must be improved) but are not sufficient and will only mitigate bottlenecks in the long run
- Significant geopolitical/supply chain risks in terms of single country dependencies for mining AND mineral processing
- Environmental, social and governance issues are a significant risk to increasing production
Mining and production is embedded in a large network of stakeholders.