Energy modeling approach to the global energy-mineral nexus: Exploring metal requirements and the well-below 2DC target with 100 percent renewable energy

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Energy modeling approach to the global energy-mineral nexus: Exploring metal requirements and the well-below 2 °C target with 100 percent renewable energy

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Two major uncertainties are addressed;
- **Scenario; 100% Renewable Energy (RE) Power mix**
- **metal req.; metal use, lifetime, recycling rate**
1. Introduction
   - background
   - Research questions

2. Methodology
   - The model
   - Scenario description

3. Results
   - Power mix (1.7DC, NC)
   - metal requirement in the energy scenarios

4. Discussion & Summary
introduction

1. Energy and climate change issues
   - Radical promotion and expansion of RE
   - < 2 degrees Celsius (DC) in Paris Agreement

2. Research Questions
   - How to attain the well below 2DC target under future energy and climate change scenarios?
   - How much scarce metals are demanded if we heavily depended on various cutting edge RE technologies?

3. Our innovations
   - Scenario flexibility; operating our own model (without borrowing ones from authorities like IEA)
   - Scenario sets; 1.7DC target under our own scenarios
   - Combination; energy-mineral nexus
very conventional but various kinds of resources

1. perfect foresight, least supply cost minimization by dynamic linear programming, meeting given final resource demands

\[
\min TC = \sum_{\xi=0}^{14} \left( \frac{1}{1+\rho} \right)^{10\xi} \cdot \sum_{rg} \left( EC_{rg,2010+10\cdot\xi} + MC_{rg,2010+10\cdot\xi} + LC_{rg,2010+10\cdot\xi} \right)
\]

2. geographical coverage; global with 10 regions
3. time horizon; 2010, 2020, …, 2150
4. “bottom-up” type with some 100 technologies
5. energy, mineral, biomass and food resources
   - fossil fuels, uranium, various renewables
   - iron ore, bauxite, copper, zinc, lead, limestone
   - logs, wood pulp, timber, meat, cereals
The model (2)

1. Interlinkages of the three resource models
   - wood and logs (land-use model) as bioenergy
   - biomass residues (land-use model) to potential supply of biomass (energy model)
   - Electricity and heat (material model) are provided from the energy model.
   - Fly-ash from pulverized coal-fired power plants (energy model) is linked to the Portland fly-ash cement process (material model).

2. A simplified climate model (from RICE 2010) is used to compute CO2 concentration from GHG emissions (energy, land-use, material models) and temperature rise.
disposal

recovery

recycling

refinery

conversion

final products

final demand

disposal

export & import via global market and regional trade (balanced globally)

extraction

harvesting

transport

refinery

conversion

final products

final demand

logistics

cost of extraction, land use, harvesting

cost of transport

cost of refinery, conversion

cost of producing final products

cost of disposal, recycling

Σ

minimizing discounted sum of cost from 2010 ... 2150

- coal, oil, gas, uranium
- iron ore, bauxite, copper, lead, zinc, limestone
- logs, wood pulp, timber, papers
- pork, chicken, mutton, beef, rice, wheat, corn
- refinery, hydrogen, FT-synfuel, methanol, ethanol, BDF, power, heat
- machinery steel, construction steel, non-ferrous metals, cement, concrete
- woods (pulp, paper, boards), foods (chicken, pork, beef, mutton)
- power, heat, transport
- vehicle, buildings, infrastructure, electricity and machinery
- fuel log, paper, boards, grains, chicken, port, beef, mutton
- coal ash, plutonium
- granulated slag, waste concrete, scraps
- biomass residue (crop residue, garbage, excrement, animal waste, logging residue, used paper, lumbering residue, black liquor)
8

Scenario description

- Climate policy
  - “1.7DC”; attaining 1.7DC by capping cumulative “net” zero emission over time, allowing an overshoot and a negative emission by large deployment of CCS.
  - “no control (NC)”; without the cap

- Energy policy
  - “Ren100”, attaining 100% RE power mix in 2100
  - “Gas&Ren”, co-existence of RE and cleaner fossil.
  - “Coal&Nuc”, pursuing efficiencies (less market volatility)

<table>
<thead>
<tr>
<th>Phasing-out</th>
<th>Resources</th>
<th>CCS</th>
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<tbody>
<tr>
<td>RE100</td>
<td>Nuc, Fossil</td>
<td>Cheap gas</td>
</tr>
<tr>
<td>Gas&amp;Ren</td>
<td>---</td>
<td>Cheap gas</td>
</tr>
<tr>
<td>Coal&amp;Nuc</td>
<td>---</td>
<td>Cheap Uranium</td>
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</table>
## Results; power mix

<table>
<thead>
<tr>
<th>Power Mix</th>
<th>20% by PV, WP, ocean</th>
<th>40% by gas</th>
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</thead>
<tbody>
<tr>
<td>40% by PV, WP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30% by bio, ocean</td>
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<td></td>
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<tr>
<td>10% by oil</td>
<td></td>
<td></td>
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<tr>
<td>20% by bio, oil</td>
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</table>

### Notes:
- When discussing power mix, always consider the percentage breakdown and the specific technologies involved.
- The focus should be on renewable and sustainable energy sources to reduce carbon emissions.
- Ensure to explain the benefits and challenges of each energy type involved.

### Diagram:
- The diagrams illustrate the generation capacity of various power sources over time.
- Key sources include renewable (e.g., solar, wind), nuclear, and fossil fuels (e.g., coal, gas).
- The x-axis represents years, and the y-axis shows power generation capacity in EJ/yr.
- The graphs show how different combinations of power mixes can impact overall energy generation and sustainability.
Results; power capacity changes under the three energy scenarios (NC, 1.7DC, and difference)
Data; metal requirements in various technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Metal</th>
<th>Intensity of use of metals for installed capacity [t/GW]</th>
<th>Lifetime</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Default</td>
</tr>
<tr>
<td>c-Si PV</td>
<td>Si</td>
<td>6630</td>
<td>638</td>
<td>20</td>
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<tr>
<td></td>
<td>Silver</td>
<td>36</td>
<td>19</td>
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<tr>
<td>CIGS PV</td>
<td>Indium</td>
<td>28</td>
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<td></td>
<td>Gallium</td>
<td>9</td>
<td>2</td>
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<td></td>
<td>Selenium</td>
<td>161</td>
<td>17</td>
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<tr>
<td>CdTe PV</td>
<td>Cadmium</td>
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<td>Tellurium</td>
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<td></td>
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<tr>
<td>Wind</td>
<td>Copper</td>
<td>2000</td>
<td>1830</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>140,000</td>
<td>135,000</td>
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<tr>
<td></td>
<td>Neodymium</td>
<td>186</td>
<td>124</td>
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<tr>
<td></td>
<td>Dysprosium</td>
<td>33</td>
<td>22</td>
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<tr>
<td>EV</td>
<td>Lithium</td>
<td>12.7 (kg/car)</td>
<td>2.4 (kg/car)</td>
<td>10</td>
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<tr>
<td></td>
<td>Cobalt</td>
<td>8.8 (kg/car)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nickel</td>
<td>46.5 (kg/car)</td>
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</tr>
</tbody>
</table>
Results; metal requirement uncertainties (PV)

* Min. sets; metal use = min, lifetime = long, recycling rate = 100% in 2100
Results; Metal requirements (FCV for hydrogen)

Note; all default sets (metal use = max, lifetime = short, recycling rate = 0%)
Thank you for your kind attentions
Questions?