Predicting emission releases from mine tailings: spatially and temporally resolved life cycle assessment modelling

Other Conference Item

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Emissions from mine tailings: spatially- and temporally-resolved life cycle assessment

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How do we quantify tailings emissions?

Legacy pollution (Lottermoser, 2010):
- Long-term emissions like ‘landfill’ (i.e., mine drainage)
- Structure stability
New models needed to estimate tailings emissions

- Geochemical model as a tool to assess long term prediction (Dijkstra, 2018)
- Tailings dataset is available in Ecoinvent, differentiated by metal type and country-level
  - Averaged concentrations, no physical & chemical interactions
- Temporal perspectives matter when dealing with long-term heavy metal emissions (Bakas, 2015)

- However, different tailings have different compositions (mineralogy)
  - Deposits origin and technology-dependent
  - Minerals can act as buffers or enhance metal releases

The necessity to consider site-specific factors
Case studies

**Input data**

Typical site in Europe, copper mining (Ecoinvent 3.5)

**Inventory, Geochemistry**

- Tailings (homogeneous)
- Metal emissions to groundwater (Cu, Zn,...)

**Impact assessment (ecotoxicity)**

- USETox 2.1
- ReCiPe 2016

Functional unit: 1 kg of tailings

Temporal choices?
Inventory (release) modelling

- Geochemical approach:
  - Integrating factors (mineralogy, climate conditions) that contribute to heavy-metals release over time
  - Complexation and dissolution/precipitation of minerals
  - Making use of comprehensive geochemical database ‘PHREEQC’ and ‘Wateq4f’ (Parkhurst, 2013; Nordstrom, 2002)
Parameterization and outputs

Site-specificity

Parameters
- Homogeneous tailings composition
- Water composition
- Matrix infiltration rate (PR)

Mineralogy
Buffers:
- Calcite
- Siderite
- Ferrihydrite
- Gibbsite

Simulation
- Leached mass of species over time ($M_{x, total}$)

$$M_{x, total} = \sum_{t=t_0}^{t_1} PR \cdot t_{\text{timestep}} \cdot (C_x(t))$$
Dissolution of minerals and major buffers over time

- Fe(OH)₃
- Al(OH)₃
- FeCO₃
- Pb(OH)₂
- Cu(OH)₂
- ZnO
- CaCO₃

Depletion time > 100,000 years
Concentrations of leachate vs. groundwater limit

In chronological order:
Calcite > Siderite > Ferrihydrite > Gibbsite

CaCO₃  FeCO₃  Fe(OH)₃  Al(OH)₃

Threshold Cu: 10.1
Threshold Cd (EU Groundwater limit): 0.2
Forward-looking LCA (USETox, freshwater ecotoxicity)

<table>
<thead>
<tr>
<th>Ecoinvent Time horizon</th>
<th>100</th>
<th>1,000</th>
<th>10,000 Years</th>
<th>60,000</th>
<th>Infinite</th>
</tr>
</thead>
<tbody>
<tr>
<td>in CTUe</td>
<td>4</td>
<td>638</td>
<td>5001</td>
<td>7570</td>
<td>8312</td>
</tr>
</tbody>
</table>

- Zn
- Cu
- Cd
- As
- Pb
Choice of LCIA methods

FU: 1 kg tailings, after 100 years and 60,000 years

**USETox, midpoint**
- **Zn**: ~2,000 times, 47%
- **Cu**: ~2,000 times, 48%
- Total: 4

**ReCiPe 2016 (H), midpoint**
- **Zn**: ~2,800 times, 31%
- **Cu**: ~2,800 times, 67%
- Total: 5E-03
Comparison of transfer coefficients after 100 years

<table>
<thead>
<tr>
<th>Species</th>
<th>Simulated (this study)</th>
<th>Ratio</th>
<th>Ecoinvent (current database)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>$3.5 \times 10^{-9}$</td>
<td>0.3</td>
<td>$1.4 \times 10^{-8}$</td>
</tr>
<tr>
<td>Cu</td>
<td>$4.5 \times 10^{-6}$</td>
<td>15</td>
<td>$3.0 \times 10^{-7}$</td>
</tr>
<tr>
<td>Zn</td>
<td>$2.2 \times 10^{-5}$</td>
<td>23</td>
<td>$9.7 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

- Differences due to consideration of thermodynamics and mineralogy inputs
- For simulated case, Cu and Zn have been completely leached out after 60,000 years
Outlook: Towards global assessment

An opportunity to improve consistency of tailings emissions

LCA of metal production

Data compiled from: USGS Minerals Resources; S&P Market Intelligence; Mudd et al 2018; Companies’ reports)
Conclusion

- The approach parameterizes the model of tailings emissions
- Geochemistry and infiltration rate control releases of heavy metals
- Possibility to include different time horizons in tailings inventory
- Choice of time horizon affects the overall LCA results
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Kindly send your questions via live chats ☺ Thanks