Introduction

Hans-Jörg Althaus

Swiss Federal Laboratories for Material Testing and Research (EMPA)
Centre for energy and sustainability (ZEN)

hans-joerg.althaus@empa.ch
contributors

- responsible institute: EMPA, Dübendorf
- project leader: Hans-Jörg Althaus
- authors: Hans-Jörg Althaus, Mischa Classen, Silvio Blaser
- contributions from: ESU-services, Niels Jungbluth
- financial support: BUWAL, BBL, ASTRA, EMPA

Main differences to ÖvE3

- Consideration of resource quality
- Consideration of slag, filter dust, overburden and tailings
- ferroalloys
- couple production
- New land use
- Meta information
- Material and processing separately
metals in ecoinvent

- iron and steel
- aluminium
- copper / molybdenum
- nickel / ferronickel
- chromium/ ferrochromium
- manganese / ferromanganese
- Platinum group metals (PGM)
- other (lead / zinc, tin, bronze, brass)
- processing

Workshop

- copper / molybdenum (Mischa Classen)
- iron / steel (Hans-Jörg Althaus)
- discussion
Non ferrous metals

Mischa Classen
Swiss Federal Laboratories for Materials Testing and Research (EMPA), Centre for Energy and Sustainability, Dübendorf
classen.mischa@gmx.ch

Content

- Nonferrous metals in ecoinvent
- Chief Differences to ÖvE3
- Data Sources

- Copper / Molybdenite: Production Chain
- Selected Results
Non Ferrous Metals in ecoinvent

- Nickel, platinum group metals (Pt, Pd, Rh), copper, molybdenum, chromium, lead, zinc, tin
- Processing: welding, rolling, drawing of wire and pipe, casting
- Auxiliary modules: tailings (dump heaps), slag disposal, infrastructure
- Use: mostly as ferroalloys (ferrochromium, ferronickel, ferromanganese)
  - Metainformations „General Comment”

Chief Differences to ÖvE3

- Tailings are included
- Modelled consistently as multi-output process (allocation by value, except for resources)
- Higher burden as compared to ÖvE3
  - Copper (swiss ecopoints) + 57% to 1.9 $10^4$ UBP / kg Cu
  - Copper (El$_{H,A}$) + 97% to 2.1 EP / kg Cu
- Increased importance of materials (infrastructure) as compared to operation phase (energy)
**Data Sources (Copper)**

- Materials & Energy
  - values for Germany 1994 (Krauss et al. 1999)
  - general process data (Ayres et al. 2002)

- Land use
  - publication in *Erzmetall* (Martens et al. 2002)

- Process specific emissions from IPPC’s BAT-report
  - copper (Rentz et al. 1999)
  - exploitation und beneficiation (IPPC 2002)

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**Copper: Consumer Mix**

- Regional consumer mix as starting point

- Characteristics:
  - imported primary copper 19%
  - regional primary copper 13% (imported copper concentrates)
  - regional primary copper 24% (regional copper concentrates)
  - regional secondary copper 22%
  - recycled copper scrap 22%

\[ = 44\% \]
Copper: Production Chain

- Primary copper, at refinery

Exploitation
  - extraction
  - beneficiation

Winning
  - pre-treatment
  - reduction
  - refining

molybdenite-concentrate (55% Mo)

SX-EW process

Copper: Winning of Primary Metal

- Technology:
  - different pyrometallurgical processes
  - varying emission factors

- Regions
  - varying concentration in ore
  - specific production technology mix
  - specific abatement technology

- Regional production mixes in ecoinvent
Copper: SX-EW

- Solvent-Extraction / Electrowinning (SX-EW) is a hydrometallurgical process
- Oxidic ores only, sulfidic ones have to be roasted previously
- Consists of exploitation, beneficiation, extraction and electrolytical winning
- Copper is dissolved with acid from ore
- Env. 10% production worldwide
- Characterised by
  - High demand in electricity
  - High land use due to leaching
  - Moderate demand in quality of the raw ore

Copper: Ore Exploitation

- Extraction
  - >90% sulfidic ores, >10% oxidic ores
  - Decreasing grades in worked deposits (1%w)
  - 30% underground mining, rest open cut with increasing trend
- Beneficiation
  - Ore is ground
  - Unwanted minerals are removed in water using chemicals
- Environmental critically issues
  - Use of cyanide (sulfidic ores)
  - Use of organic chemicals (frother, flocculant)
  - Tailings (dump heaps)
  - Land use by open cut operations / leaching heaps
Copper: Allocation of Coupled Product

- 54% of Molybdenum originates from copper-molybdenum porphyry deposits
- Two coupled products from ore exploitation
  - copper-concentrate
  - molybdenite-concentrate (MoS₂)
- Ore exploitation is modelled as multi-output process
- Allocation by value (price x output)
- Small fraction of molybdenite in output: 1.5 kg Mo-conc. / t Cu-conc.
- Split of total environmental burden as follows
  - molybdenite-concentrate = 1% US$ 3'188 / t x 5.3 kg
  - copper-concentrate = 99% US$ 522 / t x 3'480 kg
- Due to higher market price higher burden per unit (kg) is assigned to molybdenite than to copper-concentrate

Molybdenite as Main Product

- Analogous process as exploitation of copper ore (GLO)
- Differences
  - resource (0.041% Mo in crude ore, identical grade in Cu)
  - output (21 kg Mo-concentrate per t Cu-concentrate)
- Allocation
  - molybdenite-concentrate = 11% US$ 3’188 / t x 74 kg
  - copper-concentrate = 89% US$ 522 / t x 3’480 kg
- Higher burden per unit for molybdenite-concentrate compared to copper-concentrate.
- Molybdenite production mix composes of molybdenite as main product (46%) and molybdenite as coupled product from copper ore exploitation (54%)
Results: Copper-Modules - Energy

- Copper, primary, at refinery, GLO [kg]
- Copper, primary, at refinery, RNA [kg]
- Copper, primary, at refinery, RLA [kg]
- Copper, primary, at refinery, RER [kg]
- Copper, primary, at refinery, ID [kg]
- Copper, primary, at refinery, RAS [kg]
- Copper, SX-EW, at refinery, GLO [kg]
- Copper, secondary, at refinery, RER [kg]
- Copper, at regional storage, RER [kg]

Results: Copper-Modules - IPCC

- CO2-Eq.
Results: Copper-Modules - EI\textsubscript{H,A}

Results: Copper-Modules - BUWAL
Results: Consumer Mix

- Regional consumer mix of copper (RER)

<table>
<thead>
<tr>
<th></th>
<th>content</th>
<th>El_{HA}</th>
<th>UBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>imported primary copper</td>
<td>19%</td>
<td>59%</td>
<td>75%</td>
</tr>
<tr>
<td>regional primary copper</td>
<td>13%</td>
<td>14%</td>
<td>8.8%</td>
</tr>
<tr>
<td>(imported concentrate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>regional primary copper</td>
<td>24%</td>
<td>21%</td>
<td>12%</td>
</tr>
<tr>
<td>(regional concentrate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>regional secondary copper</td>
<td>22%</td>
<td>6.9%</td>
<td>4.0%</td>
</tr>
<tr>
<td>recycled copper scrap</td>
<td>22%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

Results: Production Chain - El_{HA}

Valued impacts of the production of 1 kg primary copper (GLO)

<table>
<thead>
<tr>
<th></th>
<th>El_{HA}</th>
<th>UBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Konzentrat</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>resource</td>
<td>14.1%</td>
<td></td>
</tr>
<tr>
<td>blasting</td>
<td>2.2%</td>
<td></td>
</tr>
<tr>
<td>milling</td>
<td>1.4%</td>
<td></td>
</tr>
<tr>
<td>electricity</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>additives</td>
<td>0.6%</td>
<td></td>
</tr>
<tr>
<td>particulates, &lt;2.5 um</td>
<td>6.9%</td>
<td></td>
</tr>
<tr>
<td>particulates, &gt;2.5 um</td>
<td>3.2%</td>
<td></td>
</tr>
<tr>
<td>particulates, &gt;10 um</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>heavy metals</td>
<td>0.1%</td>
<td></td>
</tr>
</tbody>
</table>

|                | El_{HA} | UBP |
| SXEW Copper    | 2.3%    |     |
| resource       | 1.7%    |     |
| blasting       | 0.5%    |     |
| milling        | 0.3%    |     |
| operation      | 0.2%    |     |
| infrastructure | 0.1%    |     |
| electricity    | 0.16%   |     |

Winning of Primary Copper

- limestone: 0.40%
- heavy oil furnace: 0.2%
- gas furnace: 0.6%
- cadmium (air): 10.4%
- nickel (air): 14.1%
- sulfur dioxide (air): 9.0%
- arsenic (air): 8.9%
- lead (air): 6.4%
- copper (air): 4.1%
- zinc (air): 2.2%

Proportion SX-EW: 9.40%

Disposal slags: 0.1%
Disposal tailings: 0.31%
Disposal: 2.1%

Particular percentages sum up to a total impact of 100%
Conclusions

- Metal emissions to air dominate pyrolytical winning.
- Particulate emissions (dust) dominate open cut mining.
- Resource depletion. Copper deposits last another 60 years.
- Tailings: marginal importance, but: long-term emissions!
- Emissions from energy production play minor role.
- SXEW: high energy use, but lower specific emissions to air.
- Molybdenite: per mass 3.7 times higher burden than copper concentrate.

Literature


Iron and Steel

Hans-Jörg Althaus

Swiss Federal Laboratories for Material Testing and Research (EMPA)
Centre for energy and sustainability (ZEN)
hans-joerg.althaus@empa.ch

content

- iron and steel in ecoinvent
- the iron and steel chain in ecoinvent
- data sources
- main differences to ÖvE3
- selected results
- uncertainties
- conclusion
- future steps
**iron and steel in ecoinvent**

- pig iron
- cast iron (electric-)
- un-alloyed steel (converter, electric, mix (reinforcing steel))
- low alloyed steel (converter, electric, mix)
- chromium steel (18/8) (converter, electric, mix)
- Processing of steel (hot and cold rolling, section bar rolling, tube and wire drawing, welding, zinc coating)

**iron and steel chain**

- land transformation & land occupation
- mine infrastructure
- buildings & machines in mine
- Building machines
- Re-transformation land, mine
- land transformation & land occupation
- open mine
- blasting, building machines, power
- mine, iron (infrastructure)
- recultivation, iron mine
- Iron ore, 46% Fe, at mine
- dust
iron and steel chain

- Iron ore, 65% Fe, at beneficiation
- sinter
- pellets
- energy
- auxillaries
- water
- emissions to water
- transport
- emissions to air
- power
- iron ore, 46% Fe, at mine

iron and steel chain

- sinter
- coal
- auxillaries
- transport
- pig iron, at plant
- water
- blast furnace
- emissions to air
- pellets
- iron ore, 65% Fe, at beneficiation
- inert waste
- waste to „sanitary landfill“
- waste water to treatment
**Presentation Hans-Jörg Althaus**

**slide 9**

**iron and steel chain**

- steel, electric, un- and low alloyed, at plant
- steel, converter, low alloyed, at plant
- hot rolling
- steel, low alloyed, at plant

**slide 10**

**data sources**

- **Mining / beneficiation:**
  - Roth et al. 1999
  - Anonymous 1998 (world bank) (water emissions beneficiation)
- **sinter and pellet production and metallurgy:**
  - Roth et al. 1999 (input materials up to pig iron)
  - IPPC 2000 (emissions, input materials (after pig iron), waste (amount, share to recycling, composition)
- **mixes: „steel at plant“**
  - IISI 2002
Main differences to ÖvE3

- New sources
- Specific chromium steel instead of “high alloyed steel” (high alloyed steel in ÖvE3 was the same steel as today but not obviously declared)
- Consideration of waste

Selected results; interpretation

- Ecological scarcity points in chain
- Ecoindicator 99 H,A in chain
- CED in chain
### CED

#### Cumulative Energetic Demand (MJ·a⁻¹)

- Non-renewable, fossil
- Non-renewable, nuclear
- Renewable, water
- Renewable, biomass
- Renewable, wind, solar, geothermal

Iron ore, 46% Fe, at mine
Iron ore, 65% Fe, at beneficiation
Sinter, iron, at plant
Pellets, iron, at plant
Pig iron, at plant
Iron scrap, at plant

### Ecological Scarcity Points

**Umweltbelastungspunkte (1997)**

- Other ecosphere
- Mercury to air
- Dioxins to air
- Cadmium, ion to water
- Particulates to air
- Other technosphere
- Steel, electric, chromium steel 18/8
- Steel, converter, chromium steel 18/8
- Steel, converter, low-alloyed
- Hot rolling
- Steel, electric, un- and low-alloyed
- Steel, converter, unalloyed
- Molybdenite
- Molybdenite, 68% Cr
- Disposal, slag, unalloyed electr. Steel
- Pig iron
- Iron scrap
- Ferronickel, 25% Ni
- Sinter
- Pellets
- Iron ore, 65% Fe
- Quicklime
- Iron ore, 46% Fe
- Electricity

**Other technosphere**
- Steel, electric, chromium steel 18/8
- Steel, converter, chromium steel 18/8
- Steel, converter, low-alloyed
- Hot rolling
- Steel, electric, un- and low-alloyed
- Steel, converter, unalloyed
- Molybdenite
uncertainties

conclusion

- direct emissions (other than CO₂) are rather relevant
- Contributions of alloying elements are relevant → specific alloys should be inventoried
- Uncertainties (not errors) are large
future steps: tailings

1% Mo in steel $\rightarrow$ UBP of steel raise to 890%
$\rightarrow$ e1 99 (H,A) of steel raise to 370%

- Nickel
- Copper (Primary, GLO)
- Molybdenite
- Steel, low alloyed, at plant

<table>
<thead>
<tr>
<th></th>
<th>in ecoinvent</th>
<th>from emissions from tailings</th>
</tr>
</thead>
<tbody>
<tr>
<td>eco-indicator 99, (H,A) [points/kg Product]</td>
<td></td>
<td>2x</td>
</tr>
<tr>
<td>ecological scarcity 1997 [UBP/kg Product]</td>
<td></td>
<td>1.5x</td>
</tr>
</tbody>
</table>