Reinventing exergy as indicator for resource depletion impacts in LCA

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Background

Assessing resource depletion

- Different methodologies exist for **quantification of resource depletion** within life cycle assessment (LCA)
- Among them, only **thermodynamic approaches consider aspects of absolute quantity** (reserves or resources contained in total in earth's crust) **and of quality** (concentration of the target element in the mined resource) [3].
- The concentration of a target metal within a given ore relative to its background concentration the principal value of the ore -> quality aspect is relevant
- However, existing approaches are either far from the original thermodynamic idea of exergy or too complex and not applicable for resource accounting.

➡ This work suggests a simple but comprehensive methodology for quantifying resource depletion related with the concept of chemical concentration exergy (MDPces). As such, it relies solely on the concentration exergy (exergy due to concentration gradients) and is not interfered by formation enthalpy. .

Approach

Calculation procedure [1]

1. determine exergy of each element due to its background concentration (following the approach by Szargut 1986 [2])
2. Determine concentration of the element within the target ore
3. Calculate exergy of the ore where the element is concentrated above the background concentration
4. Calculate depletion factor MDP^{ces}

Element	background concentration[24] (1)	concentration in ore (2)	$ces_{i,ore}$ (3)	$MDP^{ces}_{i,ore}$ (4)
Al	8.23%	24%	8.84	1.27
Au	4.00E-09	100%	95.87	253,259.81
Au	4.00E-09	4.3E-4%	65.24	3453.69
Cu	6.00E-05	0.22%	33.03	37.74
Cu	6.00E-05	0.76%	36.10	58.07
Cu	6.00E-05	1.83%	38.28	78.81
Fe	5.63%	70%	13.38	2.40
Fe	5.63%	5.63%	7.13	1
Li (Spod.)	2.00E-05	2%	43.94	174.46
Li (Brine)	2.00E-05	0.15%	37.52	70.91
Mg	2.33%	25%	15.20	3.10
Mn	0.10%	60%	33.23	38.86
Co	2.50E-05	0.20%	37.13	67.10

Table 1. MDP^{ces} values for some selected elements

Calculation method

The concentration exergy scarcity value (ces) ces_i of element i in a specific ore is calculated according to Equation 1:

$$ces_{i,ore} = -C * \ln\left(\frac{x_{i,bg}^2}{x_{i,ore}}\right) \quad \text{(Equation 1)}$$

with

- C = 2.479 (= R (gas constant) * T (normal temperature) / 1000). This constant is maintained for allowing easier comparison with other exergy-based calculations.
- $x_{i,bg}$ = background concentration of the element (avg. concentration in earth's crust) [1]
- $x_{i,ore}$ = the specific concentration of element i in the ore

The metal depletion potential is then obtained acc. to Equation 2:

$$MDP^{ces}_{i,ore} = exp((ces_i \,/\, ces_{Fe,bg}\,) -1\,) \quad \text{(Equation 2)}$$

with:

- $ces_{i,ore}$ = ces value for the element i within the specific ore
- $ces_{Fe,bg}$ = ces value for iron at background concentration

➡
- rigorous consideration of ore concentrations
- Readily applicable to existing databases (if ore concentration is considered)

Application

Application to copper production

- Calculation of MDP^{ces} for 1kg copper (market mix, ecoinvent 3.4, cut-off), no EoL
- Comparison with resource depletion impacts obtained with CEENE, CExD and $CML_{(reserve\ base)}$

Results

- Assessment of 1 kg of copper (market mix); ecoinvent 3.4.
- Contribution of elements comparable among exergy-based methodologies, CML diverges (Fig. 1)
- CES values of between 33.7 and 88.8 u/kg for copper ores (0.22% Cu and 1.83% Cu content, resp.)
- Allocation in ecoinvent not according to physical causalities -> skewed results (co-products)

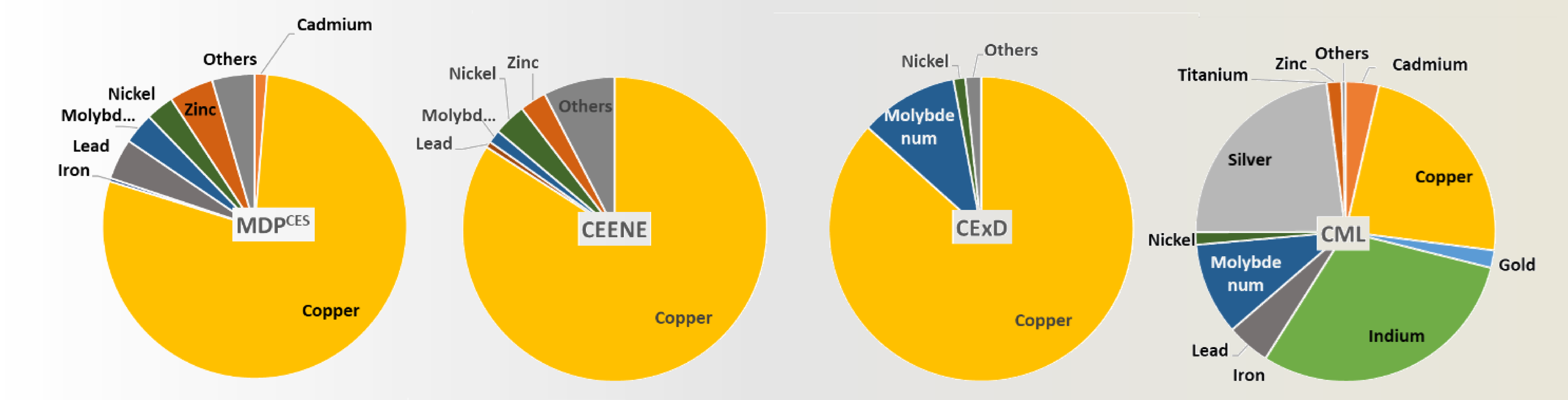

Figure 1. Contribution of major resource flows to the total metal depletion impact of 1 kg of copper metal according to the four different impact assessment methods. MDPces = concentration exergy scarcity, CEENE = Cumulative exergy extraction from the natural environment, CExD = Cumulative exergy demand and CML = abiotic resource depletion potential (reserve base) according to CML

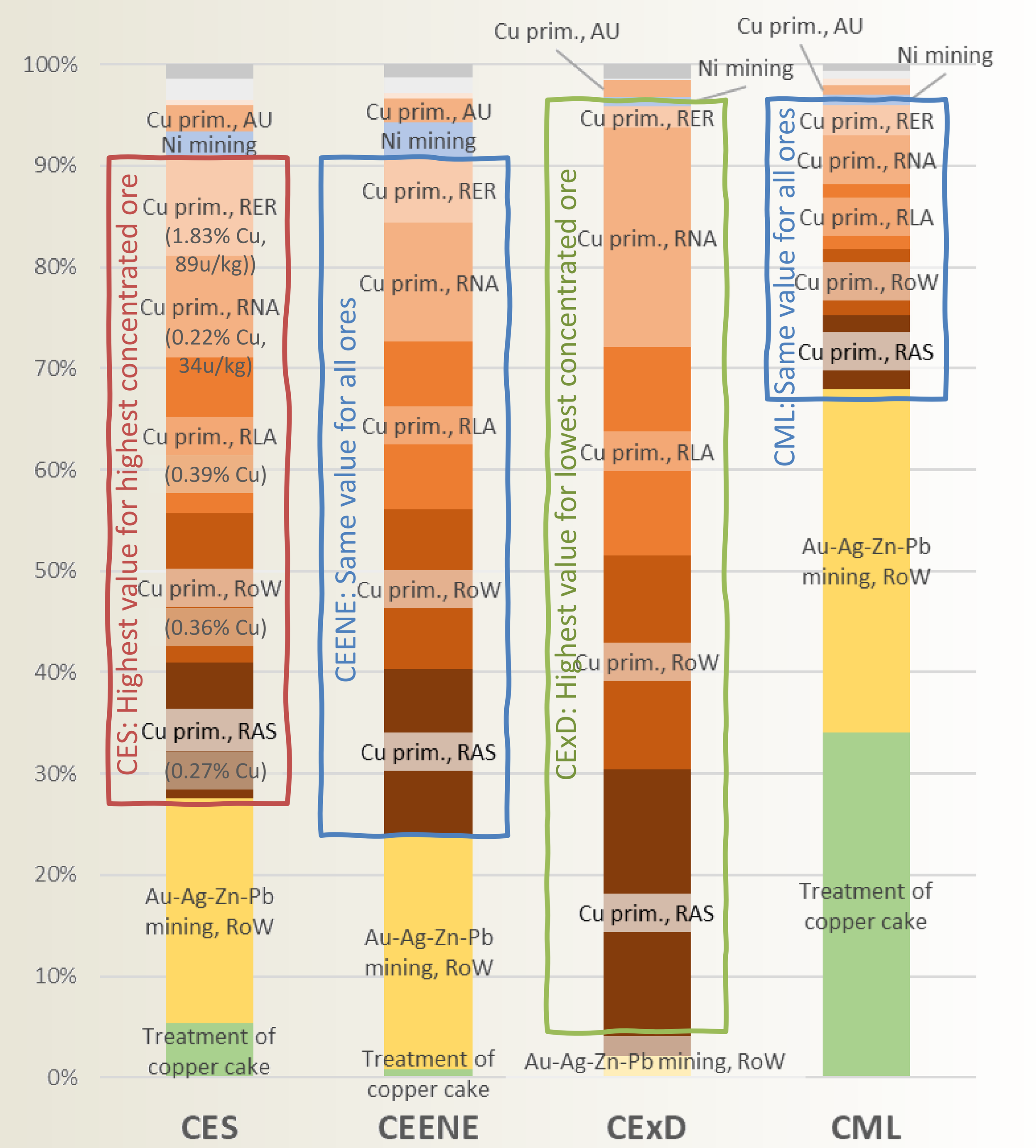

Figure 2. Major process contributions to the total resource depletion impact of 1 kg of copper metal with the different LCIA methodologies.

Outlook

- From v. 3.5 on, ecoinvent changed the assignation of elementary resource flows and does not use the ore (concentration), but only maps to the amount of metal extracted
- Need for a concentration-oriented elementary flow modelling, also for future developments towards dissipation-oriented approaches
- Compatible with dissipation-oriented approaches, case study underway..

Where we are

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References & Acknowledgements

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