Including resource security of supply in LCA: a proposal

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1. Context and scope

The security of supply of mineral raw materials has become a high-priority theme in the political agenda of many countries, especially those highly dependent on imports. At EU level, resource security is claimed as a policy objective both in the Raw Materials Initiative (EC - European Commission 2008) and within the resource efficiency policy (EC - European Commission 2011a; EC - European Commission 2011b). "Criticality" has also emerged as a research subject and different methodologies for assessing critical raw materials have been developed. Most of them are based on supply risk and vulnerability of a system to a potential supply disruption (Erdmann and Graedel 2011). Security of supply is also one of the conditions for ensuring a sustainable supply of raw materials. It is debated if environmental Life Cycle Assessment (LCA) (ISO 14044 2006) should take into account resource security, as well as other socio-economic issues related to resources or if these aspects should be included in a social LCA (Klinglmair et al. 2013; Mancini et al. 2013; Mancini et al., in press).

Nevertheless, resource security is a recurrent issue over history, mainly determined by the uneven geographical distribution of mineral reserves around the globe and the consequent import dependency in resource-poor countries (Buijs et al. 2012). This concern has recently regained importance. Global population growth, new consumption habits, technological change and economic development of some countries have enlarged the demand for raw materials both in terms of amount and variety of materials used. Some metals are increasingly relevant for emerging technologies, including those that are supposed to contribute to more sustainable societies, e.g. low carbon energy supply and transportation technologies.

Supply of raw materials can be threatened by different factors: geological, technological, geo-political, economic, environmental and social. In the criticality assessments the aspects that are commonly included are related to the raw materials markets and economy (e.g. market concentration, consumption and demand); technology (e.g. recycling potential substitutability, companion production and by-products) and geo-political (governance and political stability of producing countries). Biophysical availability of raw materials is also included in some assessments (Morley and Eatherley 2008; Erdmann et al. 2011; Graedel et al. 2012) while in others this aspect is not addressed due to the short time frame of the study, e.g. in the assessment of critical raw materials (CRM) for the European economy by the European Commission (EC - European Commission 2010; EC - European Commission 2014). In this methodology the identification of CRMs is based on two main variables: economic importance and supply risk.

Resource availability for present and future generations is a central issue in the sustainability science. In LCA natural resources represent one of the areas of protection (next to natural environment and human health). The impact related to resource use is assessed through different methods, in which limitations to the accessibility due to geopolitical reasons are usually not taken into account. The need of taking into account in LCA the economic and geopolitical aspects that can reduce resource availability has been acknowledged (Schneider et al. 2011; Mancini et al. in press). It is, however, also debated if the aspect of resource security of supply, or even socio-economic issues in general, should be accounted in so-called (environmental) e-LCA or in a (social) s-LCA (Mancini et al. 2013). An example proposal for including this concept in e-LCA is reported in Schneider (2014), where the Economic Scarcity Potential (ESP) is proposed as an aggregate indicator. It gathers eight different aspects related to the resource security (including governance, concentration of supply, application of trade barriers, demand growth, etc.) and setting thresholds of risk. EPS was calculated for 17 metals.

2. Inclusion of criticality in supply chain analysis

Having information on the use of critical resources in supply chains is very useful in eco-design contexts and policy making. This information can support and guide the minimization of CRM use, or maximization of benefits from them, their recovery in waste management and substitution. As security of supply is a socio-economic aspect, it is questionable if it should be accounted in the e-LCA (which includes a dedicated area of protection on natural resources) or in the s-LCA (where social impacts are addressed). We argue that even if the use of critical raw materials does not constitute an environmental issue per se, the current framework of e-LCA, accounting inputs and outputs in the supply chain, is most suitable for assessing the impacts linked to the use of physical resources. Indeed, the inventoried flows are measured in mass unit in e-LCA, while in the s-LCA the inventory data are accounted in dollars or working hours.

LC inventories could be readily used to analyse the use of CRM along the life cycle, relying on the outcomes of governmental critical raw material assessments. At impact assessment level indicators used for the assessment of criticality can be applied to develop characterization factors for the impact category "resource security". As outlined in Mancini et al. (2013), the main methodological hurdles and inconsistencies that have to be faced in this operation consist of: (i) the "relativity" of the criticality assessment (generally referred to a subject, a geographical region, a timeframe); (ii) the presence of elements of subjectivity (i.e. thresholds are set to establish which materials are critical); (iii) the temporary nature of the assessments (the condition of criticality can quickly change over time, even in the short run).

Proposal for the inclusion of criticality in LCA

The methodology for the identification of CRMs for the European Union combines two main variables: economic importance (EI) and supply risk due to poor governance (SR_{WGI}). The latter encompasses four sub-components: (1) level of concentration of worldwide production of raw materials (using the *Herfindahl-Hirschman Index* (HHI)); (2) political and economic stability of the producing countries (using the *Worldwide Governance Indicator*); (3) potential of substitution of the raw materials (estimated through experts' opinion); (4) recycling rate (considering the shares of EU consumption of raw materials addressed through secondary materials). A group of experts defined criticality thresholds for SR_{WGI} and EI values, which outline an area of criticality; the materials located in this area are defined as CRMs. (EC - European Commission 2014).

We argue that SR_{WGI} data provided in the EC study on CRM could be used in LCA for evaluating resources consumed in a product's life cycle in terms of resource security. In the impact assessment phase, the amounts of resources used in the supply chain (composing the inventory) can be multiplied for the SR_{WGI} factor, providing an indicator of the total resource security impact. This information could complement the existing indicator on resource depletion that does not take into account the access to resources.

The choice of supply risk as indicator allows overcoming the methodological hurdles listed above: (i) the indicators that compose SR_{WGI} (e.g. WGI and HHI) are calculated at global level (while the EI is assessed at EU level), or are based on expert judgment; recycling rate is assessed through shares of EU consumption, but these values could be substituted with global estimates on recycling rates provided by UNEP (Unep and International Resource Panel 2011) (ii) no thresholds or other subjective elements are included in this indicator (iii) frequent updates of the CFs could provide consistent assessments.

Implementation options and testing example

In LC impact assessment the input/output flows compiled in the inventory of materials consumed and emissions are quantified in terms of indicators through characterization factors[1] (CFs). An emission or resource flow is multiplied by a factor to give an indicator. The nature of the indicators varies, some reflecting contributions to impacts, risks, or pressures; some reflecting environment, health, and/or socio-economic considerations.

1 Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the impact category indicator (EC - European Commission 2011c)

SR_{WGI} data provided in the CRM study for EU could be used as CFs in a new impact category called "resource security". However, the SR_{WGI} dataset has a low variability, and the relative difference between materials in terms of security would be not well represented if these values are applied as linear weighting factors.

In order to obtain factors that could better represent the supply risk, two different options could be envisaged:

- raising the values with an exponent, that could spread the resulting values in a wider range
- dividing the values of supply risk by a measure of the size of the market, e.g. the world mine production in a given year, in order to assign more importance to specialty materials having small markets.

Three methodological options have been tested using an example dataset:

- baseline option: SR_{WGI} values as such
- option 1: (SR_{WGI})^6
- option 2: SR_{WGI}/world mine production in 2011[2]

A further option is to use the list of CRM published by the EC and apply a binary variable as CF, that assign the value 1 for the materials included in the list as critical and 0 to the non-critical ones.

The product used for testing the different options is a multi-crystalline silicon photovoltaic (PV) panel of one square metre and weight of 26 kg. The inventory includes the following raw materials: silicon, silver, aluminium, chromium, cast iron, copper, manganese, magnesium, zinc (Jungbluth et al., 2009).

Table 1 presents the results of applying the different options of CF based on SRWGI. It also includes information on the CFs resulting from the three methodological options and the amount of raw materials included in the inventory.

In terms of mass, aluminium and silicon are the most important raw materials. CFs have the same ranks in the baseline and option 1, with magnesium and silicon having the highest CF; in option 2, where mine production is taken into account, the ranking is different and silver has the highest CF.

In terms of impact result, figure 1 presents a contribution analysis of the total impact calculated with different CF sets, next to the contribution of the different metals in terms of mass and the "binary approach". In the baseline case, the contribution of silicon is the most relevant, followed by aluminium. This reflects the contribution of the raw materials in terms of mass, even though in this case the order is inverted. Using the CF from the option 1, i.e. applying the exponent 6 to the SRWGI values, the materials with the higher supply risk factor pop up, while the amount of material used has less importance; indeed magnesium is the most relevant contributor to the total

2 Data on mine production are from USGS (US Geological Survey 2011)

impact. It is noted that the choice of the exponent is arbitrary, and the variability of the results increases as higher exponents are applied, as well as the distance between the minimum and the maximum value. In this exercise the exponent 6 is chosen as an example. But, this choice is not underpinned by a biophysical law or scientific evidence. The choice rather depends on the importance one wants to assign to the risk (instead of the mass). In option 2 the supply risk relates to the size of the market, using data on mine production in 2011. This allows highlighting the materials that are used in small amounts over the bulk materials. Therefore silver has a more relevant contribution (in spite of its low mass in the inventory), together with silicon and magnesium. Due to the incomplete statistics on magnesium production (that do not include US mine production), the figure on magnesium production is underestimated and therefore the CF2 and the related impact are overestimated. In the binary approach all the impact is due to silicon and magnesium; using this approach all the materials that are not critical in the EU list are cut off, even if they have high risk values and are very close to the criticality threshold. From the other side, this method accurately reflects the policy priorities on raw materials.

Table 1: Resource security impact assessment results of a PV panel (1m^2)

Material	Input flow	Resource security impact			Characterization factors		
	mass (kg)	Baseline	SR1	SR2	CF baseline	CF 1	CF2
Silicon	1.545	2.52	28.98	3.15E-07	1.63	1.88E+01	1.40E-11
Silver	0.009	0.01	0.23	2.73E-07	0.73	1.51E-01	8.42E+00
Aluminum	2.537	1.09	0.01	2.47E-08	0.43	6.32E-03	2.53E-05
Chromium	0.008	0.01	1.64	3.37E-10	1.01	1.06E+00	4.43E-04
Cast iron	0.011	0.01	0.02	1.91E-12	0.5	1.56E-02	1.66E-06
Copper	0.115	0.03	0.00	1.58E-09	0.22	1.13E-04	2.50E-03
Manganese	0.013	0.01	0.01	4.10E-10	0.43	6.32E-03	2.35E-05
Magnesium*	0.080	0.20	405.27	2.60E-07	2.53	2.62E+02	2.48E-06
Zinc	0.005	0.00	0.01	1.94E-10	0.45	8.30E-03	3.65E-03

* USGS statistics for magnesium production do not include US production; therefore the CF2 is overestimated

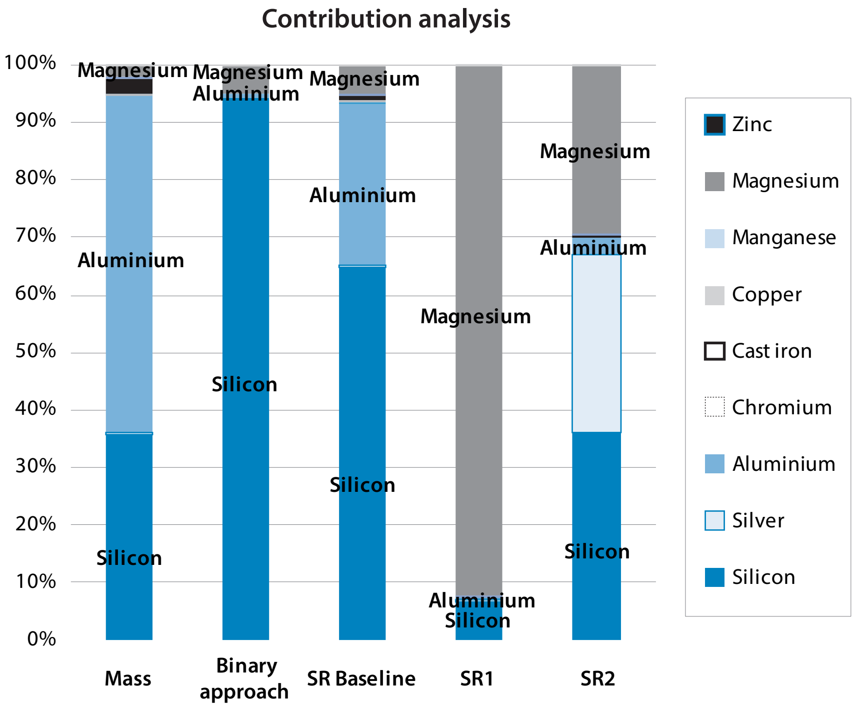

Figure 1: contribution analysis from different options for characterization

3. Conclusions

This paper suggests that so-called environmental-LCA is well positioned to include resource criticality considerations; essentially a socio-economic indicator. Separate consideration in social LCA, in relation to human flows related to product life cycles, is not needed for this particular calculation.

Different options for the calculation of resource security impact have been shown, and the outcomes of the different choices are illustrated through an example on a PV panel. Data on supply risk due to low governance used as characterization factors (baseline) does not well represent the relative difference in raw materials security, and the impact depends mainly on the masses. Applying an exponent to the supply risk dataset the values are spread on a wider range and the impact depends more on the risk factor. The choice of an exponent is arbitrary and arguable; therefore it could be established in a stakeholder consultation.

In the third option the supply risk is related to the annual mine production, which indicates the market size; this method gives more importance to specialty metals. Using a 0/1 variable for calculating the impact leads to the consideration of the materials that are defined as critical in the list published by the European Commission and the exclusion of the non-critical ones, even if their value of risk is very close to the thresholds.

Even though the choice of an option over the others is not possible at this stage and more implementation examples are needed, this exercise is expected to contribute to the discussion on the inclusion of criticality in LCA. Further analysis could be conducted including also the economic importance of materials, and comparing results with other LCIA methods and indicators.

References

Buijs B, Sievers H, Tercero Espinoza LA. (2012) Limits to the critical raw materials approach. Waste Resour Manag 165:7.

EC - European Commission (2008) The raw materials initiative - meeting our critical needs for growth and jobs in Europe.

EC - European Commission (2011a) A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. COM(2011)2:

EC - European Commission (2011b) Tackling the challenges in commodity markets and on raw materials.

EC - European Commission (2010) Critical Raw Materials for the EU. Report of the Ad-Hoc Working Group on Defining Critical Raw Materials. Brussels

EC - European Commission (2014) Report on critical raw materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials.

Erdmann L, Behrendt S, feil M (2011) Kritische Rohstoffe für Deutschland. IZT, Institut für Zukunftsstudien und Technologiebewertung Adelphi, Berlin

Erdmann L, Graedel TE (2011) Criticality of non-fuel minerals: a review of major approaches and analyses. Env Sci Technol 45:7620–7630.

Graedel TE, Barr R, Chandler C, et al. (2012) Methodology of Metal Criticality Determination. Environ Sci Technol 46:1063–1070.

ISO 14044 (2006) Environmental management - Life cycle assessment - Principles and framework. Organization for Standardization

Jungbluth N., Stucki M. and Frischknecht R. (2009) Photovoltaics. Data v2.1 In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz (ed. Dones R.). Swiss Centre for Life Cycle Inventories, Dübendorf, CH.

Klinglmair M, Sala S, Brandão M (2013) Assessing resource depletion in LCA: a review of methods and methodological issues. Int J Life Cycle Assess 1–13. doi: 10.1007/s11367-013-0650-9

Mancini L, De Camillis C, Pennington DW (2013) Security of supply and scarcity of raw materials. Towards a methodological framework for sustainability assessment. doi: 10.2788/94926

Morley N, Eatherley D (2008) Material Security - Ensuring resource availability tor the UK economy. Chester, UK

Schneider L, Berger M, Finkbeiner M (2011) The anthropogenic stock extended abiotic depletion potential (AADP) as a new parameterisation to model the depletion of abiotic resources. Int J Life Cycle Assess 16:929–936.

Unep, International Resource Panel (2011) Recycling Rates of Metals.

US Geological Survey (2011) Historical Statistics for Mineral and Material Commodities in the United States. http://minerals.usgs.gov/ds/2005/140/. Accessed 30 May 2013