Comparing Resource Use and Environmental Impacts using a LCA database

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Abstract

One of the key strategies for sustainable development is decoupling, which aims at unlinking natural resource use from economic growth. Global targets for the reduction of resource use have been set e.g. by the International Resource Panel, by the European Commission and recently a corridor for a safe operating space for global material resource use has been proposed. Regarding these targets, the question is how they can be surveyed on the micro level. Up to now, no sum parameter measuring all abiotic and biotic resources has been considered for life cycle assessment. Moreover, current life cycle assessment databases lack specific input flows to calculate all abiotic and biotic resources used by a product system.
Another reason to calculate resource use is that it can be used as a rough estimation of the overall environmental degradation induced by a product system. The environmental relevance of the resource use has been discussed controversially in the past. Currently resource use is mostly considered regarding the criticality of materials. Facing this, we developed a methodology for calculating the abiotic and biotic resource use with the indicator material footprint based on life cycle inventory data from the database Ecoinvent. The methodology was tested to analyze in how far the environmental relevance can be estimated with the material footprint by comparing the resource use with selected environmental impact categories.

Keywords

Product system, Epidermis vs Material, Comfort vs Interaction, Energy vs Communication, Industry.

Background

Decoupling, which aims at unlinking natural resource use from economical growth, can be seen as one of the key strategies for a sustainable development (UN, 2011). It has furthermore become clear that an absolute reduction of resource use is needed: Bringezu (2015) recently suggested three targets for global resource use (societal perspective) which are in line with the Sustainable Development Goals proposition by the International Resource Panel (2014). The “10-2-5 target” is meant as an orientation for policies and its target values (10 t/person of total abiotic resources used per year and 2 t/person of total biotic resources used with 5 t/person being direct raw material consumption) have a suggested resource reduction factor ranging between 4 and 10. Furthermore, Lettenmeier *et al.* (2014) suggest a sustainable resource cap target from an end user perspective of 8 t/person per year for Finnish households, which would be a reduction factor of 5 from the current state.

Regarding these targets, the question is how they can be surveyed on the micro level. Up to now, no sum parameter measuring all abiotic and biotic resources has been considered for life cycle assessment (LCA). Moreover, current LCA databases lack specific input flows to calculate all abiotic and biotic resources used by a product system. This means that the material flow analysis, which builds the baseline for macroeconomic resource calculations, and LCA are calculated based on different data and system boundaries. Therewith results are difficult to compare and bottom-up or top-down approaches are challenging.

The consideration of abiotic and biotic resource would allow calculating mass-based indicators on the micro level, which are compatible with the macro level targets. The idea behind mass-based indicators is that all anthropogenic emissions are based on the extraction of natural resources. Reducing the amount of natural resources extracted, can in consequence also lead to a lower environmental degradation induced

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by a product system (Schmidt-Bleek, 1994).

The environmental relevance of these indicators has been discussed controversially up to now. Today, LCA understands resource use and the problems associated with it are mainly regarding the criticality of resources in an economical sense (Vadenbo *et al.*, 2014; Klinglmaier *et al.*, 2014). Nevertheless, the authors of this paper still see a need to consider the resource use additionally to the measurement of specific impact categories for several reasons. In spite of the great progress in LCA's impact assessment, it is unlikely that the environmental categories proposed according to today's knowledge such as in the product environmental footprint (PEF) (Manfredi *et al.*, 2012) actually cover all environmental interventions. This was already pointed out by Klöpffer (1997) and is still valid today. For instance, Life Cycle Assessment (LCA) does not allow an reliable assessment of all environmental impacts such as biodiversity (Curran *et al.*, 2011) or impacts on land use (Mattila *et al.*, 2011).

Facing this complexity, companies and institutions can benefit from a simple mass-based indicator allowing them to measure the current state of their impact on environmental degradation without the uncertainties of ex-ante approaches, with which LCA impact assessment goes along with.

Besides all of these arguments, it seems also reasonable to consider all abiotic and biotic resources to achieve an equal mass flow balance in life cycle inventories.

Against this background, the paper presents a methodology of how to calculate the amount of abiotic and biotic resources on a product level based on LCA data using the Ecoinvent database. The adapted database is then tested analyzing the environmental relevance of the material footprint by comparing the material footprint results with other selected impact categories.

In the first part of the paper the resource indicator material footprint is introduced, followed by a detailed description of the implemented adaptions to the life cycle database. In the second part, results of the calculations of the material footprint are displayed and compared to selected impact categories. Finally, conclusions regarding similarities and differences of resource use and the selected impact categories and further need of research are given.

Methods

The following steps show how resource use was determined and compared to environmental impacts in this study:

1. Selection of a resource indicator
2. Selection of impact categories
3. Selection of a LCA database
4. Adaption of the database to calculate the resource indicator,

In this chapter each step is described in detail.

Selection of a resource use indicator - the material footprint

To assess the resource use the indicator material footprint was chosen, which is based on the MIPS (Material Input per Service Unit) concept (Liedtke *et al.*, 2014; Lettenmeier *et al.*, 2009; Ritthoff *et al.*, 2002; Schmidt-Bleek, 1998). The material footprint covers two of the five categories of the MIPS concept: the abiotic raw material and the biotic raw material, which can either be added up and used as one indicator or separately accounted for (Liedtke *et al.*, 2014). The MIPS concept takes into account the same system boundaries as the material flow analysis does (Eurostat, 2012).

The category abiotic raw material considers all mineral resources. It includes economically used resources as well as extracted but not further processed material, like overburden from mining or excavated soil during infrastructure construction.

The category biotic raw material contains all plant biomass from cultivated areas as well as plant and animal biomass from uncultivated areas. Animals from cultivated areas (e.g. cattle breeding) are accounted for by the plant biomass input for their feed. Biomass is considered with its moisture content at the time of harvest (Schmidt-Bleek, 1998). Just as for abiotic material, not only the used extraction of biotic material is considered, but all organic material that is taken from the ecosystem. Hence plant waste that is taken from the ecosystem during trimming or harvest is also considered, even if it is not further processed.

As the moisture content of a plant species can vary significantly, the specific weight can also vary depending on the cultivation conditions. A possible solution to achieve consistent results could be a standardization of the moisture content (Wiesen *et al.*, 2014).

Selection of impact categories

For a comparison of the material footprint to other impact categories, preferably ones with high impacts on nature, the default impact categories of the product environmental footprint (EU, 2013) were analyzed more closely.

It does not seem reasonable to compare the material footprint to some very specific impact categories concerning e.g. human toxicity or ecotoxicity (e.g. cancer effects, non-cancer effects, particulate matter), as these categories are not expected to be dependent on the overall amount of extracted material but are mainly linked to the use of specific chemicals or materials. Impact categories concerning water (e.g. aquatic fresh water ecotoxicity, aquatic eutrophication or water depletion) should also result in fundamentally different impacts, as the material footprint does not consider water. For the determination of these impact categories the LCIA methods pack 1.5.4 supplied by Openlca was used (OpenLCA, 2015; Acero *et al.*, 2015). In Rodriguez and Ciroth (2014) the results of impact category calculations of the ILCD method with Openlca are compared to calculations with SimaPro. These show a high correspondence for almost all categories, but especially for resource depletion the obtained results are not in accordance. Because of this and our intention to show correlations between input based and emission based calculations, the two input based indicators resource depletion and land transformation were not regarded. As a result only four out of all 14 default impact categories were selected for a comparison to the material footprint. These are: climate change (IPCC, 2007), ozone depletion (WMO, 1999), acidification (Seppala *et al.*, 2006), and terrestrial eutrophication (Seppala *et al.*, 2006). All 14 default impact categories of the Product Environmental Footprint and if and for what reason they were chosen for a comparison are shown in Table 1.

Selection of a LCA database – the Ecoinvent database

A reliable comparison of environmental impacts and resource use is only possible when using the same inventory data. For this reason using a LCA database for the determination of the indicators is the most convenient solution. At present there exists no database considering all necessary input flows for the calculation of the material footprint. Two of the biggest LCA databases in terms of number of processes are Gabi[1] and Ecoinvent[2]. They are also two of the most commonly used databases in Europe. Both contain a large set of life cycle inventory (LCI) data for basic processes e.g. for energy systems, building materials, metals, chemicals, packaging, transport services, waste treatment and agriculture and can be integrated in LCA software tools like Umberto or Openlca. Using data from

Product Environmental Footprint – Default EF Category	Correlations to the material footprint possible?
Climate Change	possible, as it concerns environmental impact
Ozone Depletion	possible, as it concerns environmental impact
Ecotoxicity for aquatic fresh water	No, as it is related to water
Human toxicity – cancer effects	No, as it is related to human toxicity
Human toxicity – non-cancer effects	No, as it is related to human toxicity
Particulate Matter/Respiratory Inorganics	No, as it is very specific
Ionizing Radiation – human health effects	No, as it is related to human toxicity
Photochemical Ozone Formation	No, as it is very specific
Acidification	possible, as it concerns environmental impact
Eutrophication - terrestrial	possible, as it concerns environmental impact
Eutrophication - aquatic	No, as it is related to water
Resource Depletion - water	No, as it is related to water
Resource Depletion – mineral, fossil	Not regarded as it is an input based indicator
Land Transformation	Not regarded, as it is an input based indicator

Table 1 – Chosen default categories of the product environmental footprint for a comparison with the material footprint

these databases increases the credibility and acceptance of environmental impact results, as the quality of the life cycle data is reliable and the origins of the data sets are transparent.

An important criterion for an adaptation is the structure of the life cycle database. Gabi is based upon system processes, which consider the entire life cycle inventory related to a product system from cradle-to-gate or cradle-to-grave in form of elementary flows[3]. This way inventories in Gabi do not allow retracing from which life cycle step the flows originate. Unit processes include elementary flows from gate-to-gate. All other inputs and outputs are included on the level of product flows, which link to other processes.

As a consequence the Ecoinvent database was chosen, because almost all processes (apart from some datasets such as plastics) are available as unit processes. As by the time of the analysis, Ecoinvent has not been available in version 3.1 yet, calculations are based on the old version 2.2. The adaptions described in this paper, however, can be carried out for version 3.1 in the same way.

As described in Wiesen *et al.* (2014) there are several challenges when adapting the database for both the calculation of the abiotic and the biotic raw materials. In the following section, the adaptions to the database are described.

Adaption of the Ecoinvent database - calculating abiotic raw material

Regarding the calculation of abiotic raw material, the Ecoinvent database only provides elementary flows from nature, which are economically used. For abiotic resources this means that:

- in metal mining processes only the net ores without tailings are considered
- in all mining processes overburden is not considered
- soil excavation e.g. for construction processes in road or building infrastructure is not available.

Saurat and Ritthoff (2013) describe, how tailings and overburden can be considered in Ecoinvent with the help of so called “unused extraction factors”. These factors relate to elementary flows from nature and are embedded in a characterization method which is implemented in the LCA software. The extraction factors are based on data published in Wuppertal Institute (2008). As described Wiesen *et al.* (2014) this approach does not yet fully meet the needs of the material footprint for several reasons:

1. Ecoinvent only provides location specific elementary flows for metals, such as nickel, copper or silver. Regarding hard coal and lignite there is only one elementary flow for each material. Table 2 shows for the example of hard coal that overburden can vary greatly depending on the country. The data show a high range from 0.75 kg/kg in China up to 17.6 kg/kg in Australia, with the world average being 4.28 kg of unused extraction per kg of hard coal (Wuppertal Institute, 2008). Hence it is necessary to add region specific values for overburden to the coal mining processes.

Country	Unused extraction factor for hard coal
Australia	17.6 kg/kg
China	0.75 kg/kg
Columbia 1	1.99 kg/kg
Germany	0.95 kg/kg
India	5.3 kg/kg
Russia 7	.3 kg/kg
South Africa 7	.56 kg/kg
USA	5.5 kg/kg
World average	4.28 kg/kg

Table 2 – Unused extraction factors of selected countries for hard coal extraction, taken from [28]

[1] Life Cycle Assessment LCA Software: GaBi Software

[2] Database - ecoinvent

[3] Elementary flows consist of resources taken from nature or emissions to nature.

2. In addition to the overburden, the material footprint also considers excavated soil (Wiesen *et al.*, 2014), which can have a significant influence especially on the abiotic resource use of infrastructure, e.g. for the construction of railway tracks, roads, airport, landfills and gas pipelines. As there is no elementary flow for soil in the current Ecoinvent version, it cannot be considered by a characterization scheme.

3. In general, the approach of using unused extraction factors in a characterization scheme results in incomplete inventories. To come to more detailed conclusions, especially when overburden and tailings are dominating the results, a possibility might be to breakdown results to unused extraction and used extraction as described Liedtke *et al.* (2014) for which the consideration of overburden and tailings is elementary flow is required.

To address the (1.) problem, overburden in coal mining processes was not considered as a factor in a characterization scheme, but a new elementary flow "soil, overburden" was defined. This way differences in mining operation due to the accessibility of the coal and the resulting amount of overburden in different regions can be taken into account. The flow was included in existing hard coal mining processes for Russia, South and Middle America, Australia, North America, East Asia, East Europe, South Africa, West Europe and China.

For all lignite mining processes only one process "lignite, at mine" was originally available in the database, even though the following processes are partly regionalized. To be able to differentiate the abiotic material input here, the process "lignite, at mine" was used to create regionalized mining processes, adapting the amount of overburden and scaling the diesel consumption accordingly. This way differences in the overburden of lignite mining are taken into consideration for Austria, Germany, Spain, France, Greece, Hungary, Macedonia, Poland, Slovenia and Slovakia.

Regarding the (2.) problem, we defined the elementary flow "soil, excavated" adding it to excavation processes included in the database. As the processes only assess excavation in m³ an average soil density of 1.8 t/m³ was used for the assessment.

Addressing the (3.) aspect, we did not succeed in including elementary flows for tailings and for overburden (apart from excavated soil and the overburden for the processes described above) in all processes, but used the characterization scheme from Saurat and Ritthoff. However, this should also be changed in the future.

Adaption of the Ecoinvent database – calculating biotic raw material

While the accounting for abiotic material lies within the system boundaries of the International Reference Life Cycle Data System ILCD and ISO (2006), the way of accounting for biotic raw materials differs from the LCA perspective. In LCA the system boundaries for agricultural processes include the crop harvested so that crops and seeds are considered to be part of the techno sphere (economy) because they are based on economically controlled processes. The Material Flow Analysis, on the other hand, which is the fundament of the material footprint, considers all biotic materials at harvest to be part of the ecosphere (nature) (Eurostat, 2012).

In the case of Ecoinvent, the database only provides biotic elementary flows for some wood types, given in m³ (Saurat and Ritthoff, 2013). These elementary flows were differentiated according to wood type (softwood, hardwood) to achieve more reliable results: It was roughly assumed that hard wood (e.g. beech) has a density of 1000 kg/m³ and softwood (e.g. spruce) a density of 800 kg/m³.

All further additional biotic flows, mainly crops, were added to the specific processes, taking into consideration the unused extraction factors, the moisture content of the plant at harvest, and if necessary the allocation factor and yields for side products. The characterization factor of the biotic raw material input MI_{biot} in kg/kg is calculated for an agricultural product P1 according to the following equation:

$$MI_{biot,P1} = \frac{Y_{P1}+Y_{P2}}{Y_{P1}} \cdot F_{alloc,P1} \cdot (1+UUE) \cdot \frac{1-w_{reference}}{1-w_{at\text{-}harvest}}$$

with Y_{P1}: Yield of product 1 in t/ha; Y_{P2}: Yield of product 2 (side product) in t/ha; $F_{alloc,P1}$: allocation factor to product 1; UUE: unused extraction factor for the plant in kg/kg; $w_{reference}$: moisture content of the product at time of reference; $w_{at\ harvest}$: moisture content of the product at time of harvest.

For some examples values are given in table 3. Yields and moisture contents were taken (Nemecek and Kagi, 2007; Nemecek and

Process in Ecoinvent 3.1 /2.2	Yield Y in t/ha	Moisture Content (w) of reference product	Moisture content w at harvest	Unused Extraction factor (UUE) in kg/kg	Allocation factor F (as used in Ecoinvent)	Material Footprint in kg/kg
Barley production, organic (grains)/ Barley grains organic	4.15	15 %	16 %	0.237	91.3 % to grains	1.947
Barley production, organic (straw)/ Barley straw organic	2.92	15 %	16 %	0.237	8.7 % to straw	0.264
Grass silage production, organic /Grass silage organic	8.10	0 %	65 %	0.1	100 %	3.143
Soybean production, organic / soybeans organic	2.81	11 %	16 %	0.36	100 %	1.441

Table 3 – Examples for the calculation of the characterization factors for abiotic resource use

metals	
Primary chromium steel	steel, converter, chromium steel 18/8, at plant
Primary low-alloyed steel	steel, converter, low-alloyed, at plant
Primary aluminum	aluminium, primary, at plant
Primary copper	copper, primary, at refinery
plastics	
PET	polyethylene terephthalate, granulate, bottle grade, at plant
High density PE	polyethylene, HDPE, granulate, at plant
paper and crops	
paper	
wheat	wheat grains IP, at farm
corn	grain maize IP, at farm
cotton	cotton fibres, at farm
Further materials	
Glass	concrete, normal, at plant
concrete	flat glass, uncoated, at plant

Table 4 – Chosen processes of the Ecoinvent database 2.2 for materials and crops for the comparison of impact categories

Schnetzer, 2011a; 2011b), allocation factors were taken from the Ecoinvent database directly and unused extraction factors taken (Wuppertal Institute, 2008). In table 4, the process names for the database in V2.2 are shown.

Testing the methodology

For a comparison of the results obtained via Ecoinvent twelve exemplary materials and crops were chosen. These consist of economical important and often used materials and products covering metals (chromium steel, low-alloyed steel, aluminum, copper), plastics (PET, HDPE), paper and crops (wheat, corn, cotton) and some further materials (glass, concrete). For the metals only metals from primary production were chosen, since there is no allocation necessary as would be for metals from secondary production. An overview of the materials and the used processes of the Ecoinvent 2.2 database are shown in Table 4.

Results and discussion

The concept of the material input should usually refer to a “service” like e.g. material input for nutrition per day, for transportation per km, or the use of a personal computer for a year. Here, materials per kg were chosen as examples, because for these the concept of abiotic and biotic material input is easiest to grasp.

Figures 1 to 4 display a comparison of the material footprint to climate change, ozone depletion, acidification and terrestrial eutrophication for some selected materials and crops. Since different impact categories have different units it is not possible to directly compare them to each other. As a workaround for the comparison the process with the highest impact in each category was scaled to a hundred percent. By doing so, the relation of the impacts of the different processes to each other can be shown. Additionally, the processes were arranged resulting in a score according to the order of the material footprint, from primary cooper with the highest material footprint to concrete with the lowest material footprint. All impacts and the specific results can be seen in Table 5.

Compared to the material footprint, the indicator for climate change especially assesses the environmental burden to be higher for processes with a high energy demand, as these normally are associated with high carbon emissions as well, as can be seen in figure 1. This is especially true for aluminum and plastic processes. As the production of aluminum needs high amounts of energy it is not unexpected that this process also has the highest impact on climate change. One of the reasons for the high impact of cotton fibers is the emission of nitrous oxide (laughing gas) due to the use of organic fertilizers, which has a much higher impact on climate change than carbon dioxide.

The values for the material footprint on the other hand are high for materials like copper that need high amounts of ore and overburden for its extraction. For this reason, the indicator for climate change assesses aluminum to be the material with the highest impact, while copper is the material with the highest material footprint. However – also considering the order of the processes – steel, paper, wheat, corn, glass and concrete are assessed similarly with both indicators.

Following the indicator for ozone depletion, aluminum is the material with the highest impact, as shown in figure 2. As ozone depletion is strongly connected to the use of some specific chemicals like chlorofluorocarbons (CFCs), al-

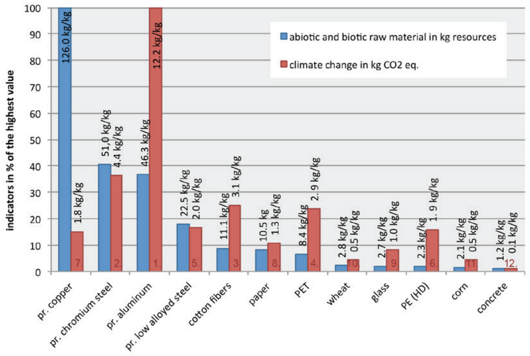

Figure 1 - Comparison of the material footprint to climate change for selected materials and crops

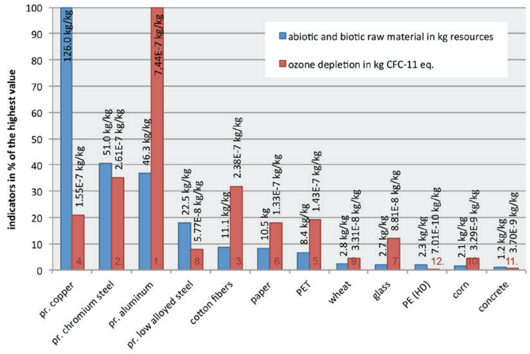

Figure 2 - Comparison of the material footprint to ozone depletion for selected materials and crops

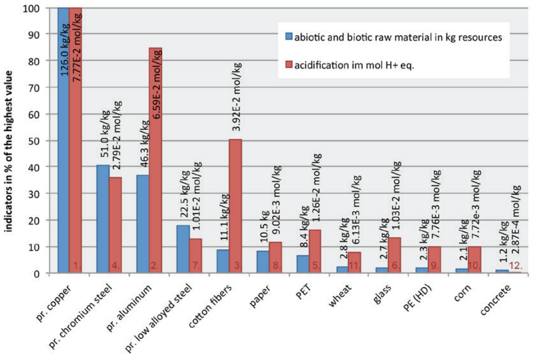

Figure 3 - Comparison of the material footprint to acidification for selected materials and crops

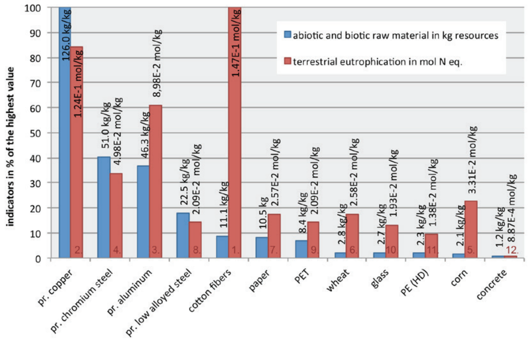

Figure 4 - Comparison of the material footprint to terrestrial eutrophication for selected materials and crops

most no similarities can be detected between ozone depletion and the material footprint. The order as well as the height of the impacts shows high differences. Apart from aluminum being the process with the highest impact, also copper, low alloyed steel, cotton fibers and plastics are evaluated differently with these two indicators. However, the three materials with the highest impact on ozone depletion: aluminum, chromium steel and cotton fibers are nonetheless within the top five materials of the material footprint.

The main drivers for acidification are combustion of fossil fuels, combustion of biomass, the deployment of organic fertilizers (Doney *et al.*, 2007) and mining (Dudka and Adriano, 1997). Hence it is not unexpected that for most of the selected materials the two indicators show similar impacts, as is shown in figure 3. Both the material footprint and the indicator for acidification assess primary copper as the material with the highest impact of the chosen materials. Still, the impact of especially cotton fibers and aluminum on acidification is higher compared to the material footprint.

Cotton fibers have the highest impact on terrestrial eutrophication (as shown in figure 4), as their production needs huge amounts of fertilizers which are one of the main sources of nitrogen (Smith *et al.*, 1997). Especially the impact of cotton, paper, wheat and corn on eutrophication is indicated to be higher than their impact on resource use, but nonetheless of the three processes with the highest impact on terrestrial eutrophication (cotton fibers, copper and aluminum) two are not agriculturally based and all three are also evaluated with a high material footprint (top five). For the agriculturally based processes the biotic resources make up a big part of the material footprint: 76 % for corn, 72 % for wheat, 33 % for paper and 24 % for cotton fibers.

Conclusion

Adaption of the Ecoinvent database

To determine the material footprint using the life cycle database Ecoinvent, several adaptions to the database were necessary: Soil excavation related to infrastructure construction as well as waste rock and overburden from mining activities have been taken into account. Furthermore, new elementary flows for crops have been added. Upcoming updates of the database should, if possible, include these additions defining new elementary flows for abiotic unused extraction e.g. (e.g. “soil, overburden”, “rock, tailings”, “soil, excavated”) and for plant species (e.g. “potato, at harvest”). These inputs should, of course,

Impact category:	**Material footprint**	Climate change	Ozone depletion	Acidification	Terrestrial eutrophication	Average score in impact categories
Unit:	**kg resources**	kg CO_2 eq	kg CFC-11eq	mol H^+ eq	mol N eq	–
per kg material/crop						
copper	**1**	7	4	1	2	3.5
	126.0 kg	1.8 kg	1.55E-7 kg	7.77E-2 mol	1.24E-1 mol	–
chr. steel	**2**	2	2	4.	4	3
	51.0 kg	4.4 kg	2.61E-7 kg	2.79E-2 mol	4.98E-2 mol	–
aluminum	**3**	1	1	2	3	1.75
	46.3 kg	12.2 kg	7.44E-7 kg	6.59E-2 mol	8.98E-2 mol	–
low-all. Steel	**4**	5	8	7	8	7
	22.5 kg	2.0 kg	5.77E-8 kg	1.01E-2 mol	2.09E-2 mol	–
cotton fibers	**5**	3	3	3	1	2.5
	11.1 kg	3.1 kg	2.38E-7 kg	3.92E-2 mol	1.47E-1 mol	–
paper	**6**	8	6	8	7	7.75
	10.5 kg	1.3 kg	1.33E-7 kg	9.02E-3 mol	2.57E-2 mol	–
PET	**7**	4	5	5	9	7.5
	8.4 kg	2.9 kg	1.43E-7 kg	1.26E-2 mol	2.09E-2 mol	–
wheat	**8**	10	9	11	6	9
	2.8 kg	0.5 kg	3.31E-8 kg	6.13E-3 mol	2.58E-2 mol	–
glass	**9**	9	7	6	10	8
	2.7 kg	1.0 kg	8.81E-8 kg	1.03E-2 mol	1.93E-2 mol	–
HDPE	**10**	6	12	9	11	9.5
	2.3 kg	1.9 kg	7.01E-10 kg	7.76E-3 mol	1.38E-2 mol	–
corn	**11**	11	10	10	5	9
	2.1 kg	0.5 kg	3.29E-8 kg	7.72E-3 mol	3.31E-2 mol	–
concrete	**12**	12	11	12	12	11.75

Table 5 - Overview of results for all investigated impact categories by amount and score (lowest score is the best)

also be considered on the output side providing complete and comprehensible inventories.

There are some limitations and challenges remaining, which are addressed in the following:

- Regarding the flows for overburden and tailings, ores with a high ore grade are less and less available so that the average ore grade decreases over the years. Hence, the related flows need to be updated over the years and cannot be seen as set values.

- To improve the accuracy of the results for the material footprint the number of regionalized processes has to be increased, as e.g. the amount of overburden in hard coal extraction in Germany can differ greatly from that in China. This would improve the data quality for other indicators as well, because further flows such as energy use are also influenced by the amount of overburden.

- A shortcoming of the methodology is the rough assumption regarding the density of wood and soil. The densities should be specified step by step whenever a dataset is updated.

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Calculation results

As second part of the analysis, the adapted database was tested regarding the environmental relevance of the material footprint by comparing the material footprint results with other selected impact categories. This comparison is not very extensive, but allows some first conclusions regarding the environmental relevance of the material footprint: As the top three materials with the highest impacts of each impact category are within the top five materials of the material footprint (as shown in table 5), it can be assumed that the material footprint indicates an environmental relevance.

Moreover, some specific conclusions can be drawn:

- Metals with a low ore content and materials related to a high amount of overburden show a high relevance for the material footprint.

- Energy intensive materials are evaluated with a lower environmental relevance compared to climate change.

- Compared to terrestrial eutrophication the material footprint shows lower impacts for materials and processes linked to agriculture.

- Generally, acidification and the material footprint display a similar trend since mining, resource extraction for fossil fuels and the use of biomass have a high influence on both resource use and acidification.

- As ozone depletion is strongly connected to the use of some specific chemicals like CFCs, almost no similarities can be stated.

The next step to extensively analyse the environmental relevance of the material footprint should be a correlation analysis for all Ecoinvent processes and impact categories. This could be done with the help of software tools such as Brightway (2015), which allows extended graphical visualisations and has been tested with Ecoinvent.

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