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Correlation analysis of life cycle impact assessment indicators measuring resource use

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Abstract
Introduction Even though the necessity of a sustainable use of natural resources is widely accepted, there is neither consensus on how “resource use” is clearly defined nor how it should be measured. Depending on the definition, it can comprise raw material consumption only or the consumption and pollution of natural resources. Consequently, lots of indicators can be applied, and the result of a life cycle assessment study aiming to quantify resource use seems to depend on the selection of impact categories. Therefore, this paper aims at analyzing life cycle impact assessment results obtained by means of several indicators to check if different indexes lead to similar results and if the number of indicators can be reduced.
Methods Life cycle impact assessment results of 100 materials from the GaBi and ecoinvent databases were compiled using the GaBi 4.3 software. The results obtained by different resource- and emission-oriented as well as single-score indicators were compared by means of correlation analysis to check for potential dependencies between indicators.
Results and discussion The analyses revealed large differences regarding the correlations between indicators. While no significant correlations were found between emission-oriented indexes (R^2=0.40–0.62), strong linear regressions were identified between indicators assessing raw material consumption (R^2=0.65–0.98). This can be explained by the facts that all indicator results are dominated by the consumption of fossil fuels and that characterization models of correlating indexes rely on net calorific values when computing characterization factors for fossil energy carriers. In material groups that consist of energy carriers themselves, like monomers and polymers, significant linear regressions were identified between all resource-oriented indicators (R^2=0.78–1.00).
Conclusions Depending on the definition, different life cycle impact assessment indicators can be used for measuring resource use. Following the broader definition, a wide range of impacts has to be evaluated as no significant correlations between indexes assessing resource consumption and pollution were identified. In contrast, since strong linear regressions were revealed among some resource-oriented indicators, the number of indexes can be reduced when defining resource use in a conventional sense.

Keywords Correlation analysis · Dependencies · Indicators · Life cycle impact assessment · Resource use

1 Introduction

The sustainable use of natural resources is an important step for achieving a sustainable development of our society. This thought is widely accepted and accommodated in several political panels and strategies, e.g., in the “International Panel for Sustainable Resource Management” (UNEP 2010) and the “Thematic Strategy on the sustainable use of natural resources” (EU 2005). When putting the idea of a sustainable resource use into daily practice, it is important to enable its concrete measurement. Indexes are needed to quantify “resource use” in order to allow for a comparison

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of different options or to document the effectiveness of measures that aim at promoting a sustainable use of resources. While this necessity is widely agreed on, there is currently no consensus on which indicators should be used to measure resource use. A reason for this can be found in the inconsistent definition of the term “resource.”

In a conventional sense, a resource is defined as “A concentration of naturally occurring solid, liquid, or gaseous material in or on the earth’s crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible” (USGS 2010). Based on this definition, physical indexes like mass and material input per service unit (Ritthoff et al. 2002), or impact assessment indicators such as abiotic depletion potential (Guinee et al. 2002), could be used to quantify resource use. Another resource definition has been introduced in the “Thematic Strategy on the sustainable use of natural resources” (EU 2005). Accordingly, resources are defined as “raw materials such as minerals, biomass and biological resources; environmental media such as air, water and soil; flow resources such as wind, geothermal, tidal and solar energy; and space (land area).” The question which indicator(s) should be used to measure resource use according to this broader definition, comprising consumption and pollution of natural resources, is more complex and was recently addressed in a study commissioned by Eurostat (Van der Voet et al. 2009). The authors evaluated different single-score indicators, such as environmentally weighted material consumption (Van der Voet et al. 2005), concerning their suitability to measure resource use on a macro-economic level of nations or industrial sectors. On a detailed micro-economic level, resource use of products or processes can be analyzed by means of life cycle assessment (LCA) (ISO 14040 2006; ISO 14044 2006), which provides a large number of indicators for assessing raw material consumption and environmental pollution. Hence, life cycle impact assessment (LCIA) indexes such as abiotic depletion, acidification, eutrophication, or global warming potentials (Guinee et al. 2002) allow for measuring resource use according to the conventional and broader resource definition.

Taking into account the different definitions and the various LCIA indicators available, it can be assumed that the result of a LCA study aiming to quantify resource use is strongly dependent on the resource definition and on the choice of indicators. Therefore, this paper aims at comparing LCIA results obtained by means of different impact categories focusing on resource consumption and/or the pollution of natural resources. Correlation analyses are conducted to check for dependencies between indicator results and to analyze if different indicators lead to similar findings. If this is the case, the number of indicators that has to be evaluated for quantifying resource use can be reduced as they provide similar results. If not, a consensus on how resource use should be measured will have to be reached for public policy applications, as otherwise the “sustainable use of natural resources” would stay a rather vague concept.

2 Methods

Life cycle inventories (LCI) of 100 materials from the GaBi database were analyzed by means of the GaBi 4.3 software (PE International 2010). As correlations between indicators might vary depending on the material type, the same number of 25 materials from the four main material groups divided in the GaBi software was chosen to avoid certain material groups from being over- or underrepresented (Table 1).

The environmental impacts per kilogram of the materials listed above were analyzed by means of the following LCIA indicators assessing the consumption and/or pollution of natural resources:

- Primary energy demand (PED) from non-renewable resources (PE International 2010)
- CML 2001, abiotic depletion potential (ADP) (Guinee et al. 2002)
- CML 2001, global warming potential (GWP), 100 years (Guinee et al. 2002)
- CML 2001, eutrophication potential (EP) (Guinee et al. 2002)
- CML 2001, photochemical ozone creation potential (POCP) (Guinee et al. 2002)
- Ecological Scarcity Method 1997 (ESM97) (BUWAL 1998; PE International 2010)
- Eco-indicator 99, hierarchist approach (EI99) (Goedkoop and Spriensma 2001)

There are many other indicators available for assessing raw material consumption and environmental pollution, like cumulative exergy demand (Bösch et al. 2007), methods addressing water use (Berger and Finkbeiner 2010), human- and eco-toxicity potentials (Guinee et al. 2002), or ReCiPe (Goedkoop et al. 2009). In this work, the focus was put on indicators which are frequently applied in LCA studies. Moreover, there was a restriction to use those indicators available in the GaBi 4.3 software, as otherwise it would have not been possible to accomplish a survey comprising such a large number of materials. Hence, all conclusions drawn in chapter 5 should be seen under this restriction.

The results obtained by means of the seven indicators were compared with each other by means of correlation analysis. Potential dependencies were described more in detail using regression analysis (Papula 2001). However, it has to be mentioned that not all of the 100 materials were included. The production of some materials causes an extremely

Table 1 Materials analyzed in the correlation analysis

Ores, metals, alloys	Monomers and polymers	Organic intermediates	Inorganic intermediates
Aluminum ingot	Acrylonitrile butadiene styrene pellets	Acetone	Ammonia
Aluminum alloy ingot (AlSi7Mg)	Ethylene	Acetic acid	Ammonium chloride
Aluminum alloy sheet (AlMgSi1)	Ethylene propylene diene elastomer	Benzene	Argon
Aluminum hydroxide	Epoxide resin	Benzine	Azotic acid
Brass	Fiber glass	Bisphenol A	Calcium carbonate
Cadmium	Natural rubber	Butadiene	Calcium hydroxide
Copper	Polyamide 6 pellets	Cumene	Calcium oxide
Ferrochrome	Polyamide 6.6 pellets	Cyclohexane	Carbon dioxide
Ferromanganese	Polybutadiene pellets	Diesel	Carbon monoxide
Ferronickel	Polycarbonate pellets	Ethanol	Chlorine
Gold	Polyester resin	Ethyl benzene	Hard coal
Lead	Polyethylene (HD) pellets	Ethylene glycol	Hydrochloric acid
Magnesium	Polyethylene (LD) pellets	Formic acid	Hydrogen
Manganese	Polyethylene terephthalate	Formaldehyde	Hydrogen cyanide
Nickel	Polymethyl methacrylate	Glycerol	Hydrogen fluoride
Palladium	Polyphenylene sulfide	Isopropanol	Hydrogen peroxide
Platinum	Polypropylene pellets	Kerosine	Lignite
Rhodium	Polystyrene	Maleic anhydride	Nitrogen
Silicium	Polyurethane foam	Methane	Oxygen
Silver	Polyvinyl alcohol	Methanol	Soda
Steel (non-alloyed)	Polyvinyl chloride	Natural gas	Sodium chloride
Steel (high alloyed)	Polyvinyldene chloride	*O*-xylol	Sodium hydroxide
Tinplate	Propane	Phenol	Sodium sulfate
Tin	Sheet molding compound	Toluol	Sulfur
Zinc	Styrene	Urea	Sulfuric acid

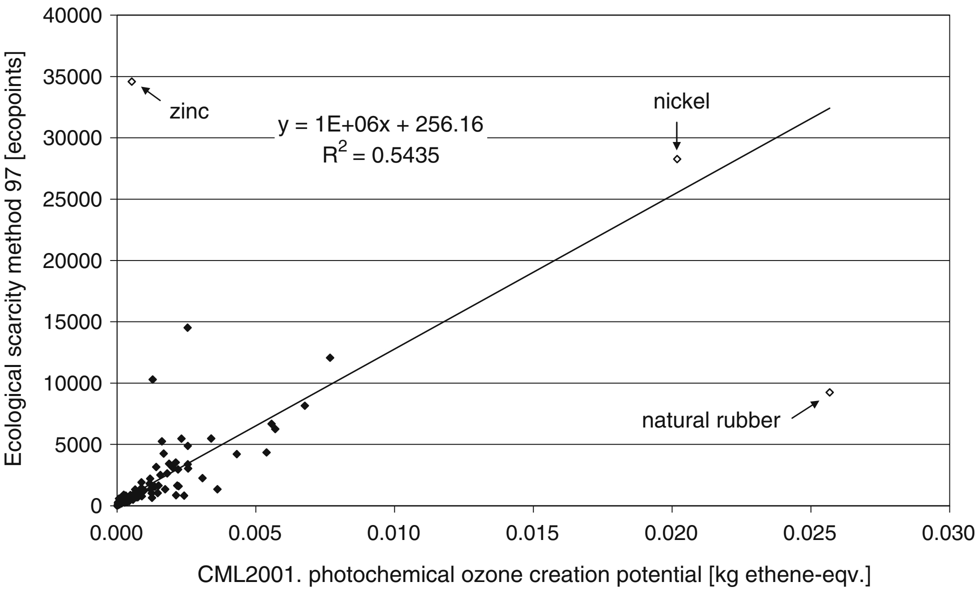
strong environmental impact that is up to 6,000 times higher than the impact of the other materials. Consequently, only these materials would have influenced the result of the correlation analyses while the impacts of the remaining materials would have been negligible. Additionally, single materials were far outside of the scatter plot in certain indicator combinations. As shown in Fig. 1, such outliers do not reflect the overall trend and can either reduce the coefficient of determination (R^2) (like zinc and natural rubber) or increase it (like nickel) significantly. This would imply non-realistic correlations and, thus, such individual outliers were excluded from the analyses, too. It is mentioned in the respective tables, which materials were excluded in all or in particular indicator combinations.

In order to exclude database dependencies, the correlation analysis was repeated using the ecoinvent (ecoinvent Centre 2010) database. The LCI for the same materials were compiled, and the same LCIA indicators were evaluated. Only in some cases, where a material from the GaBi database was not available in the ecoinvent database, a similar material was selected. As, in a conventional sense, resource use comprises the consumption of raw materials only, a further correlation analysis was accomplished. LCI of the same 100 materials from the GaBi database were assessed by means of the following resource-oriented LCIA indicators:

- PED from non-renewable resources (PE International 2010)
- CML 2001, ADP (Guinee et al. 2002)
- EDIP 1997, resources (EDIP97re) (Hauschild and Wenzel 1998)
- Surplus energy based on EI99, hierarchist approach (SE) (Goedkoop and Spriensma 2001)
- Input fraction of Ecological Scarcity Method 1997 (ESM97in) (BUWAL 1998, PE International 2010)

Finally, the analysis was repeated, and this time, correlations were analyzed for the four material groups separately instead for a material mix.

Fig. 1 Linear regression between POCP and ESM97 for 100 materials from the GaBi database excluding the outliers natural rubber, nickel, and zinc



3 Results

The results of the correlation analysis of LCIA indicators assessing resource use according to the definition of the European Union, as consumption and pollution of natural resources, are shown in Table 2 for the GaBi and in Table 3 for the ecoinvent databases. Results are considered as similar and correlations as strong or significant, if the coefficient of determination is greater than 0.65. Significant correlations are printed in italics.

When defining resource use in a conventional sense and evaluating indexes assessing raw material consumption only, the following correlations were identified for the material mix.

As shown in Table 4, indicator combinations containing EDIP97re do not show any dependencies. Therefore, the correlation analysis was repeated once more with a non-normalized EDIP97re index ($\text{EDIP97re}_{\text{non-norm}}$). The coefficients of determination between the results along with the corresponding scatter plots and regression line are presented in Table 5.

In order to verify the findings shown in Table 5, the correlation analysis was repeated and dependencies were analyzed for the four material groups separately instead for a material mix (Table 6).

4 Discussion

4.1 Correlation analysis of indicators measuring resource consumption and pollution

The correlation analyses of LCIA indicators assessing resource consumption (PED and ADP), the pollution of natural resources (GWP, EP, and POCP), and both together (ESM97 and EI99) revealed varying correlations between indicators. While significant linear regressions were identified between PED and ADP (R^2=0.97–0.98), no such strong

Table 2 Coefficients of determination (R^2) between LCIA results obtained by means of seven impact indicators for 100 materials from the GaBi database

	PED	ADP	GWP	EP	POCP	ESM97	EI99
PED	1	*0.98*	*0.70*	$0.38^{a,b}$	$0.47^{a,c}$	$0.21^{c,d}$	*0.85*^{a,c,d,e}
ADP		1	0.64	$0.33^{a,b}$	$0.42^{a,c}$	$0.18^{c,d}$	*0.85*^{a,c,d,e}
GWP			1	$0.62^{a,b}$	$0.61^{a,c}$	$0.49^{c,d}$	*0.70*^{a,c,d,e}
EP				1	$0.49^{a,b,c}$	*0.67*^{a,b,d}	$0.48^{a,b,d}$
POCP					1	$0.54^{a,c,d}$	$0.42^{a,c,d}$
ESM97	Excluded in every combination: gold, silver, palladium, platinum, rhodium, cadmium, magnesium					1	$0.34^{c,d}$
EI99							1

The footnote symbols indicate the individual outliers that were excluded from the respective linear regression analysis: [a] Natural rubber; [b] Steel (high alloyed); [c] Nickel; [d] Zinc; [e] Polyvinyldene chloride

Table 3 Coefficients of determination (R^2) between LCIA results obtained by means of seven impact indicators for 100 materials from the ecoinvent database

	PED	ADP	GWP	EP	POCP	ESM97	EI99
PED	1	*0.97*[a]	*0.77*[b]	0.39	0.63[c,d,e]	0.35[d,e]	0.64[d,e,f,g]
ADP		1	*0.71*[a,b]	0.37[a]	0.60[a,c,d,e]	0.26[a,d,e]	0.58[a,d,e,f,g]
GWP			1	0.50[b]	0.58[b,c,d,e]	0.42[b,d,e]	0.63[b,d,e,f,g]
EP				1	0.40[c,d,e]	0.31[d,e]	0.23[d,e]
POCP					1	0.47[c,d,e]	0.41[c,d,e]
ESM97	Excluded in every combination: gold, silver, palladium, platinum, rhodium, polyphenylene sulfide, silicium, tin, tinplate					1	0.56[d,e]
EI99							1

The footnote symbols indicate the individual outliers that were excluded from the respective linear regression analysis: [a] Cadmium; [b] Magnesium; [c] Natural rubber; [d] Copper; [e] Nickel; [f] Brass; [g] Ferrochrome

correlations were revealed between indicators assessing the pollution of natural resources (R^2=0.40–0.62). Also, correlations between resource-oriented and emission-oriented indicators are not that strong (R^2=0.37–0.77), which is also valid for dependencies between single-score indexes (ESM97 and EI99) and emission-oriented indicators (R^2= 0.23–0.70). The strongest variations were identified between single-scores and resource-oriented indicators (R^2=0.18–0.85). In order to explain the significant linear correlations between EI99 and PED as well as ADP in the GaBi database (R^2=0.85), a significance analysis of the EI99 results was accomplished. The analysis revealed that the overall EI99 results are often dominated by the consumption of fossil energy carriers—even though fossil and mineral resource consumption only account for 20% of the weighting in the hierarchist perspective (Goedkoop and Spriensma 2001). The resulting strong correlations are explained in detail in Section 4.3, where the linear regressions between SE (input fraction of EI99) and ADP as well as PED are discussed.

When comparing the correlations obtained by the analyses of the GaBi and ecoinvent databases, it can be seen that the linear regressions in half of the indicator combinations are almost equal. In about one quarter of the combinations, R^2 increases and in another quarter, the coefficient of determination decreases. Some of these changes can be explained by the different database formats. For instance, in contrast to GaBi, ecoinvent contains land use information, which is taken into account in the ESM97 version incorporated in the GaBi software and, thus, changes the correlations in comparison with those identified by means of the GaBi database.

The rather weak correlations between many of the indicators are also interesting in terms of the current carbon footprint discussion (Finkbeiner 2009). Obviously, a single impact category cannot reflect the complex environmental consequences of a product system. With regard to the measurement of resource use, the selection of indicators has a high impact on the result—at least when the broader resource definition of the European Union is applied.

4.2 Correlation analysis of indicators measuring resource consumption only

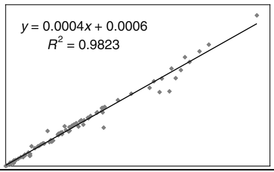
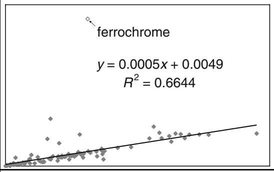
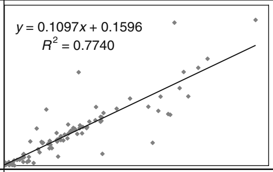
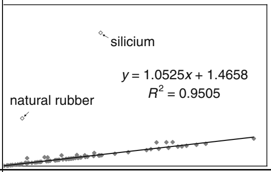
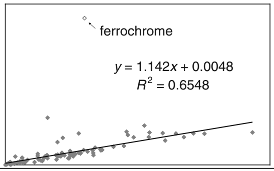
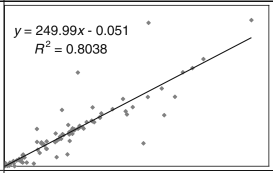
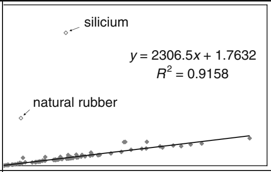
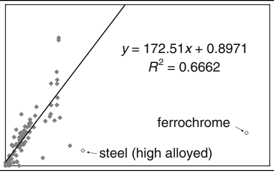
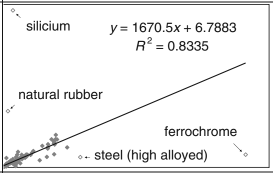
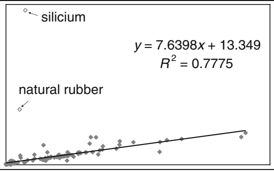
When defining resource use in a conventional sense as raw material consumption, significant linear regressions (R^2=0.65–0.98) were identified between all resource-oriented indicators analyzed (PED, ADP, $\text{EDIP97re}_{\text{non-norm.}}$, SE, and ESM97in) in the material mix. It should however be noted that only the non-normalized EDIP97re results lead to strong correlations with the other indicators because the normalization depends on an economic resource extraction in a reference year and does not reflect any physical scarcity. When analyzing correlations for the four material groups individually instead of for the material mix, diverse results were obtained.

Table 4 Coefficients of determination (R^2) between LCIA results obtained by means of five resource-oriented impact indicators for 100 materials from the GaBi database

	PED	ADP	EDIP97re	SE	ESM97in
PED	1	*0.98*	0.00	*0.77*	*0.95*[a,b]
ADP		1	0.00	*0.80*	*0.92*[a,b]
EDIP97re			1	0.00	0.00
SE	Excluded in every combination: gold, silver, palladium, platinum, rhodium, cadmium, magnesium			1	*0.78*[a,b]
ESM97in					1

The footnote symbols indicate the individual outliers that were excluded from the respective linear regression analysis: [a] Natural rubber; [b] Silicium

Table 5 Scatter plots and R^2 between LCIA results obtained by comparing five resource-oriented impact indicators for 100 materials from the GaBi database

	PED	ADP	$\mathrm{EDIP97re}_{\text{non-norm.}}$	SE	ESM97in
PED	1				
ADP		1			
EDIP $97\mathrm{re}_{\text{non-norm.}}$			1		
SE		Excluded in every combination: gold, silver, palladium, platinum, rhodium, cadmium, magnesium		1	
ESM97in					1

Strong linear regressions (R^2=0.84–1.00) throughout all material groups have been identified between PED, ADP, and ESM97in leading to the conclusion that it is sufficient to evaluate only one of these indicators. In this case, the LCA practitioner is free to choose an index, which can be easily determined and which is easy to understand. For instance, PED, which is expressed in MJ and calculated by simply multiplying raw material inputs by net calorific values, might be a more convenient indicator than ADP—measured in the rather abstract unit of kilogram antimony equivalents.

In contrast to PED, ADP, and ESM97in, the significant correlations between the remaining indicators identified in the material mix (Table 5) were not revealed in all four material groups. For instance, the strong overall linear regression between ADP and SE determined in the material mix (R^2=0.80) ranges from a coefficient of determination of 0.96 in "monomers and polymers" to 0.36–0.38 in the three other material groups.

4.3 Rationale for correlations

An explanation for the significant linear regressions revealed in some of the indicator combinations can be found in the underlying methodologies, which have already been discussed in a previous work (Berger and Finkbeiner 2008).

The strong linear correlations between PED and ADP (R^2= 0.95–1.00) are surprising at first sight as material inputs are multiplied by their net calorific values or by characterization factors denoting their respective scarcity. Since the material inputs are constant, one might conclude that there must be a correlation between net calorific value and scarcity. However, there is a methodological explanation for this phenomenon. First, a significance analysis accomplished for all ADP results revealed that the ADPs of the 100 materials are dominated by the consumption of fossil energy carriers to a magnitude of more than 95%. Second, Guinee et al. (2002) provide a general characterization factor for fossil energy (4.81×10^{-4} kg Sb-eqv./$\mathrm{MJ}_{\text{fossil}}$) rather than for single energy carriers arguing that fossil fuels are substitutes and, thus, should be characterized equally. As ADPs of fossil fuels are calculated by multiplying the general ADP for fossil energy by the net calorific value of individual energy carriers, there must be a significant linear regression between PED and ADP. Being aware of the fact that the overall ADP result is dominated by the consumption of fossil energy carriers, the method developers have recently split the impact category into $\mathrm{ADP}_{\text{elements}}$ and $\mathrm{ADP}_{\text{fossil fuels}}$ (CML 2010).

The strong correlations between PED and ESM97in (R^2= 0.92–1.00) can be explained in a similar way. The version of ESM97in incorporated in the GaBi software (BUWAL 1998,

Table 6 Coefficients of determination (R^2) between LCIA results obtained by means of five resource-oriented impact indicators for 25 materials from four material groups of the GaBi software

		PED	ADP	EDIP 97re$_{non\text{-}norm.}$	SE	ESM97in
Ores, metals, alloys	PED	1	*0.95*	0.36[a]	0.34	*0.92*[b]
	ADP		1	0.41[a]	0.38	*0.84*[b]
	EDIP97re$_{non\text{-}norm.}$			1	0.25[a]	0.43[a,b]
	SE	Excluded in every combination: gold, silver, palladium, platinum, rhodium, cadmium, magnesium			1	0.43[b]
	ESM97in					1
Monomers and polymers	PED	1	*0.99*	*0.92*	*0.94*	*1.00*[c]
	ADP		1	*0.90*	*0.96*	*0.99*[c]
	EDIP97re$_{non\text{-}norm.}$			1	*0.78*	*0.91*[c]
	SE	Excluded in every combination: –			1	*0.93*[c]
	ESM97in					1
Organic intermediates	PED	1	*1.00*	*0.85*	0.42	*1.00*
	ADP		1	*0.83*	0.36	*0.99*
	EDIP97re$_{non\text{-}norm.}$			1	*0.67*[c,d]	*0.85*
	SE	Excluded in every combination: glycerol			1	0.42
	ESM97in					1
Inorganic intermediates	PED	1	*0.97*	0.58	0.40	*1.00*
	ADP		1	0.48	0.36	*0.97*
	EDIP97re$_{non\text{-}norm.}$			1	0.17	0.59
	SE	Excluded in every combination: hydrogen, hydrogen cyanide			1	0.41
	ESM97in					1

The footnote symbols indicate the individual outliers that were excluded from the respective linear regression analysis: [a] Ferrochrome; [b] Silicium; [c] Natural rubber

PE International 2010) only accounts for the consumption of non-renewable energy carriers and land use. As there are no land use information in the GaBi database, ESM97in only comprises energy consumption and, consequently, correlates with PED (R^2=0.92–1.00).

There is no such easy explanation for the linear regressions between EDIP97re$_{non\text{-}norm.}$ and PED as well as ADP in the material groups of monomers and polymers (R^2=0.90–0.92) and “organic intermediates” (R^2=0.83–0.85). A significance analysis revealed that most EDIP97re$_{non\text{-}norm.}$ results are dominated by the consumption of energy carriers as well. However, in contrast to ADP, Hauschild and Wenzel (1998) do not provide a general characterization factor for fossil energy that is “translated” into fossil resource specific factors based on their net calorific values. Moreover, correlations are significantly lower in the other two material categories (R^2= 0.36–0.58) even though their EDIP97re$_{non\text{-}norm.}$ results are energy-dominated, too. Obviously, the fact that LCIA indicator results are dominated by the consumption of fossil energy carriers does not necessarily lead to a significant correlation between the LCIA indicator and PED.

The diverse correlations identified in the indicator combinations containing SE (R^2=0.17–0.94) are difficult to explain as well. Surplus energy is defined as the additional energy required to mine remaining resources of lower concentration, after a resource extraction took place (Goedkoop and Spriensma 2001). This concept is quite abstract and different from the methodology of, e.g., PED. Therefore, a significant linear regression between SE and PED (R^2=0.94) in the material group monomers and polymers is surprising. A further significance analysis accomplished for the results obtained by means of SE revealed that, again, the consumption of fossil fuels is influencing the overall result by more than 80% in all material groups. The fact that a strong correlation has been revealed in only one material group supports the theory that energy-dominated indicators do not automatically correlate with PED.

5 Conclusions

The necessity of a sustainable use of natural resources is widely accepted in industry and policy. However, since the definition of the term resource use ranges from raw material consumption only to the consumption and pollution of natural resources, a broad range of indicators can be applied to measure resource use in LCA. As both a consistent definition and a measuring method are currently lacking, this work aimed at analyzing correlations between LCIA indicators to check if results of a resource use study are dependent on the selection of indexes and if the number of indicators can be reduced. LCI of 100 materials from the GaBi and ecoinvent databases were compiled and analyzed by a set of LCIA indicators measuring raw material consumption, environmental pollution, and both. The results obtained were compared by means of correlation and linear regressions analyses to check for potential dependencies between indicators. The analyses revealed significant linear regressions between indicators assessing raw material consumption (R^2=0.65–0.98). The strongest correlations were identified between PED, ADP, and ESM97in showing coefficients of determination between 0.84 and 1.00 in all material groups. This phenomenon can be explained by the facts that all indicator results are dominated by the consumption of fossil fuels and that characterization models of these correlating indexes rely on net calorific values when computing characterization factors for fossil energy carriers. Furthermore, correlations are higher for those material groups which consist of energy carriers themselves, like monomers and polymers or organic intermediates. In contrast, the analysis did not identify such significant correlations between emission-oriented indexes assessing the pollution of natural resources (R^2=0.40–0.60). Consequently, lots of indicators have to be evaluated when measuring resource use according to the broader definition of the European Union comprising resource consumption and pollution. Taking into account the significant correlations between some resource-oriented indexes, the number of indicators that has to be analyzed when defining resource use in a conventional sense can be reduced as they lead to similar findings.

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