Normalization in Life Cycle Assessment: consequences of new European factors on decision making

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Abstract. Environmental performance assessment of products supply-chain is necessary to improve sustainability in companies. Life Cycle Assessment (LCA) is a powerful but little used tool for this purpose. Normalization is an optional step of LCA according to ISO 14040/44 to rank the impacts of a system. This paper studies the use of the International reference Life Cycle Data System (ILCD) normalization factors to reduce risks and uncertainties of normalization in a European context. Based on a case study of urban furniture product made with composite materials, we compare two characterization methods. Normalization with ILCD shows important differences of the normalized results for several impact categories comparing to normalization with older methods, which may have consequences on business decisions. We conclude on the importance of using the latest available methods to assess the environmental impacts of a system and on the need to link these approaches or metrics with supply-chain performance evaluation models.

Keywords: Life cycle impact assessment (LCIA), Normalization, ILCD, Decision making, Multi-criteria.

1. Introduction

Performance evaluation of supply-chains has been largely studied, but remains a promising field of research. Nowadays, the concept of sustainable development has become a key element of this area. There is a need of new methods in the field of metrics for sustainable supply-chains, and of tools for their integration in assessment models. Life Cycle Assessment (LCA) is a powerful method in environmental performance measurement because it considers the entire life cycle of a product or a service and it measures their impacts with the use of multi-indicators. According to ISO standard 14040 [1], the method is based on principles like transparency, and it gives priority to scientific approach, making it a widely used tool. However, LCA is usually not used to assess the sustainability of supply-chain management practices [2]. The public usually considers it as a complicated method whose results are difficult to understand.

This paper studies normalization methods as a tool to examine the importance and magnitude of Life Cycle Impact Assessment (LCIA) results, to communicate on these results, and as a decision support tool for businesses. Several methods are available for normalization and it is not always easy to know which one a LCA-analyst may use to reduce risks and uncertainties. Based on a case study, we show the consequences on strategic decisions if one uses old normalization methods. Conclusions highlight the necessity for companies to incorporate LCA metrics into supply-chain design and models.

The remainder of this paper is organized as follow: Section 2 introduces LCA methods and the normalization concept. Section 3 highlights the difficulties and limits with the normalization of environmental LCA results. We propose in Section 4, an approach based on the new International reference Life Cycle Data System (ILCD) Handbook produced by the Institute for Environment and Sustainability in the European Commission Joint Research Centre (JRC) [3] to reduce uncertainties. Finally, we conclude in Section 5 on the importance of using the latest available methods to assess the environmental impacts of a system and on the need to link these approaches with supply-chain performance evaluation models.

2. The normalization for the interpretation of environmental LCA results

2.1. LCA, a powerful but complex decision support methodological tool for the companies

Many methodologies and tools are available to perform an environmental analysis of a product or a service system.

We can distinguish:
- Mono-criteria analyzes that focus on one type of environmental impact (eg the Bilan Carbone® tool developed by ADEME [4] that looks only at the greenhouse gases emissions);
- Multi-criteria analyses that use different environmental impacts (eg LCA).

As a multi-criteria quantitative and transparent methodology based on a scientific approach, LCA is a powerful decision support methodological tool for the environmental management of industries and the environmental management of supply-chain. According to ISO standard 14040 [1], there are four phases in an LCA study: 1) the goal and scope definition phase, 2) the inventory analysis phase, 3) the impact assessment phase, and 4) the interpretation phase. The phases three and four allow to identify the hot spots where the product system or the service system under study can be improved all along its life cycle. These hot spots are identified using impact categories, which represent environmental issues of concern (eg climate change, acidification, human toxicity, etc.). Many impact category indicators quantify these impact categories. LCA results may vary and may include errors due to system boundary definition, to data uncertainty and to data hypothesis because of data gap [5].

Different LCIA methods have been developed to characterize the elementary flows crossing the boundary of the studied system into impact categories (third phase of an LCA study). The most accepted and most used characterization methods for LCIA convert the inventoried flows into impact category indicators at the midpoint level (they measure the potential impacts of the studied system unlike the endpoint methods which measure the potential damages to the human health and the ecosystems). Among the available midpoint characterization methods in Europe, we compare in this study the three following methods:
- CML [6], one of the first more complete and most commonly used method;
- ReCiPe H [7], an enriched (from CML) and harmonized method;
- ILCD [3], the latest method.

The LCIA method chosen to characterize the input and output elementary flows may add uncertainties to the LCA results [8]. However, choosing a method for calculating environmental impact of a "product-system" is not always obvious. In addition, LCIA results are not always easy to understand for a non-LCA expert. In general, a LCA end-user, which is a non-expert would prefer to have a unique indicator (e.g. the single "ABC…G" European Union energy efficiency label of electric products [9]). Nonetheless, using a single indicator is not the purpose of a Life Cycle Assessment. A LCA analyst may have difficulties to rank the impact categories used in a same method to select only the ones representing the greatest impact on the environment. Indeed, how to make a ranking of impact categories that do not measure the same thing (e.g. how to compare the impact of global warming and the impact of acidification)? This is the reason why the International Organization for Standardization (ISO) standard 14044 [10] provides an optional process to compare several impact category indicators. This option called Normalization is presented in the next section.

2.2. Interest of the normalization for the interpretation of environmental LCA results

As defined in the ISO standard 14044, normalization is a process to calculate the magnitude of the results of impact category indicators, relative to some reference information. It is an optional process that can be done to complement a LCIA. The characterized results of each impact category are divided by a selected reference value, which brings all the results on the same scale (see equation 1).

$$N_i = S_i / R_i , \qquad (1)$$

where, i is the impact category, N_i is the normalized results, S_i is the characterized impact of the impact category i of the system under study, and R_i is the characterized impact of the impact category i of the reference system.

The reference system can be:

- The total inputs and outputs for a geographical given area over a given reference year (e.g. the impact of the European Union for 2010);
- The total inputs and outputs for a geographical given area over a given reference year on a *per capita* basis (e.g. the impact of a European in 2010).

Examples of normalization references:

- CML: EU25+3, 2000 (impact in 2000 of the 25 European Union countries of 2006 + Iceland, Norway and Switzerland) [11];
- ReCiPe H: Europe ReCiPe H, 2000 (impact of Europe in 2000) [12].

Normalization can be helpful in interpreting LCIA results, providing and communicating information on the relative significance of the impact category indicator results [13]. The normalization results will be more understandable for a non-LCA expert because it is closer to its personal preoccupations: it makes the understanding of the environmental impact of a product easier when one can compare it to the environmental impact of one person during a full year.

3. Difficulties and limits with the normalization of environmental LCA results

Normalization is an interesting tool, but according to the chosen characterization method and the chosen reference system, LCIA results can vary and therefore one may not take the right decisions using it. Equation 1 shows that the normalization is calculated dividing the impact of a system under study by the impact of the reference system. Uncertainties may exist on both the numerator and the denominator due to some incompleteness. They can come from the category indicator results of the product under study, or from the reference system [14]; therefore, the results of the normalization can be too low or too high. We can have some bias because of the following data:

- Uncertainties from the LCIA model (see Section 2.1), and from the number of considered substances in the model;
- The reference geographical area of the reference system that can be consistent or not with the area of the studied system;
- The reference year of the reference system that can be consistent or not with the study;
- The number of considered substances in the reference system.

We have shown in Section 2 that it is not easy to quickly compare LCIA characterization methods because they do not always have the same impact categories and they can use different impact category indicators. The only common impact category among all methods is the “climate change”. For this impact category, the Intergovernmental Panel on Climate Change (IPCC) [15] developed a globally recognized model. It calculates the radiative forcing of all greenhouse gas, which is measured using the Global Warming Potentials (GWP) expressed as a factor of carbon dioxide (CO_2). In the present section, we compare two LCIA methods (CML and ReCiPe H) that measure the GWP of substances for the 100 year time horizon (which is the basis adopted for the Kyoto Protocol).

The LCA tool used for this study is openLCA [16] and it includes CML and ReCiPe H. Both methods calculate the climate change based on the GWP factors extracted from the fourth assessment report of the IPCC published in 2007 [17]. Consequently, we should have the same LCIA results regardless of the method. However, LCIA calculation gives different results using CML or ReCiPe H. These differences are explained by:

- A different numbers of greenhouse gas elementary flows included in the model: CML (359 elementary flows), ReCiPe H (461 elementary flows);
- A different strategy for the characterization of the wooden products impact: CML method uses a negative impact factor (positive impact for the global warming) for the agriculture and forestry growing products (carbon dioxide consumption during the growing period more important than the carbon dioxide rejection during the product life-cycle). On the contrary, ReCiPe H does not have any negative impact factors.

Therefore, the normalization factors for CML method and for ReCiPe H method are different (see Table 1).

Table 1: CML and ReCiPe H characterization factors and normalization references

"Climate Change" impact category Unit : kg CO2 eq./kg	**CML**	**ReCiPe H**
Number of characterization factors	359	461
Normalization references	EU25+3, 2000	Europe ReCiPe H, 2000
Normalization factors	5,21E+12	8,15E+12

This confirms that the LCIA results will be different depending on the LCIA methods used for a LCA study [18]. Consequently, the normalization calculation will also give different results (see Equation 1). These differences will even be amplified if each LCIA method uses different normalization references and normalization factors.

The limits and uncertainties of the normalization process can create different interpretation of LCA results, which can result in serious consequences for the environmental strategy of a company. The classification of indicators inside LCA may give the impression to end-users that some environmental impacts are more important than others. There is a risk of ignoring some environmental impacts and therefore to plan environmental strategies towards some strategic choices rather than others. This can go against the interest of LCA: to use a multi-criteria tool to avoid impact transfer from an impact category to another one.

4. An approach based on new ILCD normalization factors to reduce uncertainties

4.1. The International Reference Life Cycle Data System (ILCD) Handbook

The ILCD Handbook is a guide produced by the Institute for Environment and Sustainability in the European Commission Joint Research Centre (JRC) [3] on best practices in LCA. Published in 2010, it provides LCA experts with recommendations to make quality LCA and to use the best LCIA methods in the European context. It is a consensus of different methods, both in midpoint and endpoint [19]. It is actually the most up-to-date and the most complete method to perform LCIA in Europe but until 2014 there was no normalization factors proposed for it. This is not anymore the case since the JRC published in 2014 a document with recommended normalization factors for the EU-27 related to the domestic inventory in 2010 [20], see Table 2.

Table 2: ILCD recommended normalization factors for the EU-27 [20]

Impact category	Unit[1]	Domestic	Normalization Factor per Person (domestic)	Overall Robustness
Climate change	kg CO_2 eq.	4,60E+12	9,22E+03	Very High
Ozone depletion	kg CFC-11 eq.	1,08E+07	2,16E-02	Medium
Human toxicity - cancer effect	CTUh	1,84E+04	3,69E-05	Low
Human toxicity - non-cancer effect	CTUh	2,66E+05	5,33E-04	Low
Acidification	mol H+ eq.	2,36E+10	4,73E+01	High
Particulate matter/Respiratory Inorganics	kg PM2.5 eq.	1,90E+09	3,80E+00	Very High
Ecotoxicity for aquatic fresh water	CTUe	4,36E+12	8,74E+03	Low
Ionising radiations – human health effects	kBq U235 eq. (to air)	5,64E+11	1,13E+03	Medium
Photochemical ozone formation	kg NMVOC eq.	1,58E+10	3,17E+01	Medium
Eutrophication - terrestrial	mol N eq.	8,76E+10	1,76E+02	Medium
Eutrophication - freshwater	kg P eq.	7,41E+08	1,48E+00	Medium to Low
Eutrophication - marine	kg N eq.	8,44E+09	1,69E+01	Medium to Low
Land use	kg C deficit	3,74E+13	7,48E+04	Medium
Resource depletion - water	m^3 water eq.	4,06E+10	8,14E+01	Medium to Low
Resource depletion - mineral, fossil & renewable	kg Sb eq.	5,03E+07	1,01E-01	Medium

The domestic inventory (third column) represents the total emissions of the EU-27 countries in 2010. Per person normalization factors (fourth column) have been calculated using Eurostat data on the EU-27 population in 2010 (domestic inventory divided by 499 million inhabitants). The robustness gives the confidence in the quality of data and methods used to calculate the normalization factors; it is based on the level of maturity of the scientific approach to measure the environmental impacts (we have more perspective on the assessment of global warming than the assessment of human toxicity of all chemical substances).

4.2. Application with a case study

In the scientific literature, many LCA studies have been done using ReCiPe H normalization factors [21], [22], but it is not the case for the ILCD normalization factors. The normalization for ILCD is too recent and is not yet included inside LCA tools.

We conducted our LCA study on an urban furniture product made with composites materials, and used openLCA. The company needs to develop an eco-design tool to perform LCA analysis to communicate with its customers on the product environmental impacts, but did not know which impact categories to use. For this purpose, we first updated our LCA database with the ILCD normalization factors and we applied them on the LCIA results of our product. This analysis gave us the opportunity to compare the ILCD normalization results with the results previously obtained with the ReCiPe H normalization factors. For the two analyses, we fixed all the LCA parameters and models. So the results variations can only be explained by the differences between ReCiPe H and ILCD characterization methods and normalization

[1] kg CO_2 eq. (kg equivalent in CO_2), kg CFC-11 eq. (kg equivalent of trichlorofluoromethane), CTUh (comparative toxic units for human), mol H+ eq. (equivalent molar concentration of the hydrogen ion), kg PM2.5 eq. (kg equivalent of particulate matter with diameter under 2.5 µm), CTUe (comparative toxic units for ecosystem), kBq U235 eq. to air (equivalent uranium radiation measured in kilo Becquerel), kg NMVOC eq. (kg equivalent of non-methane volatile organic compounds), mol N eq. (equivalent molar concentration of the nitrogen atom), kg P eq. (kg phosphorus equivalent), kg N eq. (kg equivalent nitrogen), kg C deficit (soil organic carbon deficit in kg), m^3 water eq. (equivalent volume of water), kg Sb eq. (kg equivalent of antimony).

methods. The normalization results are presented in Tables 3 (the impact categories description have been harmonized between ReCiPe H and ILCD to help the comparison).

Table 3 : ReCiPe H and ILCD normalization results for the case study

Impact category	Amount normalization Europe 2000 (ReCiPe Midpoint H)	Amount normalization EU27 2010 (ILCD)
Human toxicity	5,69E-11	2,40E-10
Ionizing radiation	6,01E-12	4,84E-11
Freshwater ecotoxicity	2,88E-10	4,14E-11
Marine eutrophication	4,47E-11	3,54E-11
Particulate matter	1,14E-11	2,58E-11
Photochemical ozone formation	8,89E-12	2,53E-11
Climate Change	1,43E-11	2,39E-11
Acidification	1,36E-11	1,89E-11
Freshwater eutrophication	4,31E-11	1,71E-11
Ozone depletion	6,04E-13	8,91E-13

There are differences between the normalized impacts calculated by the two methods. Table 4 presents the variations between ReCiPe H results and ILCD results.

Table 4: Ranking comparison of ILCD and ReCiPe H normalization results

Impact category ILCD	ILCD ranking	ReCiPe H ranking	Indicator variation ILCD vs. ReCiPe
Human toxicity	1	2	322%
Ionizing radiation	2	9	705%
Freshwater ecotoxicity	3	1	-86%
Marine eutrophication	4	3	-21%
Particulate matter	5	7	127%
Photochemical ozone formation	6	8	185%
Climate Change	7	5	67%
Acidification	8	6	39%
Freshwater eutrophication	9	4	-60%
Ozone depletion	10	10	47%

Differences were expected, as the normalization reference year is 2000 for ReCiPe H and 2010 for ILCD. Regarding the ionizing radiation impact category, differences are given by a different total impact of domestic inventory (the LCIA results are the same with ILCD or ReCiPe H). The JRC Technical Report [20] gives explanation on the fact that ReCiPe H reference system leaded to a large overestimation of radioactive emissions. The same reason explains the ranking difference for the Freshwater eutrophication: different choice in the modelling of the domestic inventory [20] (whereas the LCIA result is the same).
However, this explanation is not valid for some other important variations. Using ILCD method instead of ReCiPe H method causes an important increase of the normalized results for the impact categories affecting the "human health" endpoint impact category: human toxicity, particulate matter, photochemical ozone formation. These differences confirm the important level of uncertainties for the characterization and the normalization of some impact categories. For the "Human toxicity" impact category, studies have shown that there is a lack in the characterization factors with the ReCiPe H method [23, 24]. The UNEP (United Nations Environment Program) and SETAC (Society for Environmental Toxicology and Chemistry) recommendation is to use the USEtox^{TM} model and factors [25], which is included in the ILCD method. This leads to the conclusion that the ReCiPe H characterization method for the "Human toxicity" impact category is now obsolete.

These results may totally change the conclusions of a life cycle interpretation and the decisions taken based on a LCA report. If one does not take into account some indicators, some strategic decision can change, such as the choice of materials, the choice of energy mix, the choice of transport mode, etc. This can have consequences on the eco-design strategies inside a company, and even on a global supply-chain.

5. Conclusions and future research

LCA is a powerful method in environmental performance measurement. Normalization is an optional step in Life Cycle Assessment. However, it is a very interesting tool to study the relative importance and magnitude of the results of impact category indicators, and it can be used to present LCIA results for an internal use in a company or a supply network. Nevertheless, the use of normalization has to be done with an awareness of its risks and limits. The analyst must understand the chosen LCIA method and its associated normalization factors and must be able to evaluate its uncertainties and gaps. He also has to use the most appropriate normalization references in function of the system under study. Then he must clearly inform LCA end-users about the limits of the results and their interpretations. For these reasons, it is important to use the latest available methods to assess the environmental impacts of a system. As illustrated in the case study, we recommend using the ILCD Handbook for LCA in Europe, which propose a consensus of methods to realize LCIA: the ILCD method and its normalization factors are the most up-to-date even if the quality must be improved for some impact category indicators. Research has still to be done to fill-in the gaps and improve the models [20]. Normalization factors for specific area or specific countries are also expected to perform more precise LCIA.

Supply-chain performance evaluation models rarely use LCA methods and indicators. From an experimental point of view, case studies are expected with ILCD method and its normalization factors in order to have more examples of LCA uses with supply-chains. Links should be created between the two fields of research in order to improve the assessment of supply-chain from a sustainability point of view. LCA approaches could be considered as good practices for the improvement of the design or management of supply-chains.

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