Search for the environmental indicators relevant for the building sector

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Abstract: Life cycle assessment (LCA) is an internationally recognised methodology to calculate the environmental impact of goods and services. It is widely used to estimate the environmental impact of building products. Despite the general acceptance of the life cycle approach and the methodological steps (i.e. goal and scope definition, inventory, impact assessment, evaluation and interpretation), there is still a lot of debate on specific methodological issues. This paper focuses on one important challenge, namely the choice of environmental impact categories and corresponding indicators to be considered for the assessment of buildings and building products. More specifically, this paper discusses the balance to be found between assessment efficiency and comprehensiveness. Based on the experience in several LCA studies of buildings and building related products in the Belgian and French context, the identified relevant indicators are presented and discussed. The lessons learned are described and recommendations are formulated.

Keywords: building sector, efficiency, environmental indicators, holistic assessment

Introduction

Life Cycle Assessment (LCA) is a widely used approach to calculate the environmental impact of buildings and building products. This is reflected in several norms (e.g. EN15804 (1) and EN15978 (2)) , guidelines (e.g. EeB Guide (3)) and simulation tools (e.g. GreenCalc (4), e-tool (5), e-LICCO (6), IES-VE (7)). Different databases moreover exist with environmental data of building products based on the LCA method (e.g. NIBE (8), OVAM-MMG (9) and EPDs (10) in general). Unfortunately these decision-supporting instruments use amongst others different system boundaries, different life cycle inventory data, different indicators, different impact assessment models and hence are not consistent. This leads to confusion and makes it difficult to interpret and to compare the environmental impacts of buildings and building related products.

This paper focuses on the selection of environmental indicators. The aim is to contribute to the ongoing discussion on relevant indicators for the building sector. The paper reports the outcome of several research projects, both in Belgium and France and compares their outcomes regarding the relevance of the environmental indicators. The assumption is that it will be easier to interpret LCA studies of buildings and building products once we have a better insight in the relevance of the different indicators. It is furthermore assumed that a more limited set of indicators would lead to less contradictory indicators and hence could avoid the need for subjective weighting. Moreover, this insight could on the longer run contribute to a
harmonisation of indicators considered in the different available standards, methods, tools and databases.

In the subsequent section the different impact assessment methods considered within the research projects are described. This is followed by an analysis of the relevance of the impact categories and a discussion of the results of the different studies. Finally, conclusions are drawn and recommendations formulated.

**Impact assessment methods in selected research projects**

*SuFiQuaD – Sustainability, Financial and Quality evaluation of Dwelling types (BE)*

In the SuFiQuaD project a methodology was developed to assess the life cycle environmental impact and financial cost of building products and buildings. The method developed was moreover applied to optimise 16 representative residential buildings from an environmental and financial perspective. Further information on this project can be found in the PhD thesis of Allacker (11) and final project report (12).

In the environmental impact assessment 17 indicators are considered, subdivided in six key-pollutants (i.e. CO$_2$-eq., SO$_2$, NO$_X$, VOC, PM2.5, NH$_3$,) and eleven impact categories (i.e. carcinogens, respiratory effects organics, respiratory effects inorganics, climate change, radiation, ozone layer depletion, ecotoxicity, acidification/ eutrophication, land use, depletion of minerals and depletion of fossil fuels). Double counting between the key pollutants and the impact categories is avoided. To calculate a single score these 17 indicators are all expressed in environmental external costs. The external costs were determined based on a combination of several methods (13), (14), (15), (16), (17). For a description of the monetary valuation in the SuFiQuaD project we refer to a publication of Allacker and De Nocker (18).

*OVAM:MMG - Environmental Profile of Building elements (BE)*

The aim of the OVAM:MMG project was to develop a method to assess the environmental impact of building elements (to be extended in future to buildings) and to develop a database with the environmental profile of several building element (e.g. outer wall, inner wall, flat roof, foundation, etc.) solutions.

The environmental impact assessment in the OVAM:MMG project is an update of the SuFiQuaD method and distinguishes two sets of indicators. The first set consists of the seven EN15804 (1) indicators (i.e. climate change, ozone depletion, terrestrial acidification freshwater eutrophication, marine eutrophication, photochemical oxidant formation and metal depletion) and the second set consists of eight additional indicators based on the recommendations in the ILCD handbook (19) (i.e. human toxicity, particulate matter formation, ionising radiation (human health), terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, land occupation – forest, urban land occupation and land transformation tropical rain forest). A single score is calculated by expressing all environmental impacts in environmental external costs. For a detailed description of the OVAM:MMG project and its environmental impact assessment we refer to the project report (9).
e-LICCO: evaluation tool for Low Impacts and Costs Constructions (FR)
e-LICCO is an online software for LCA studies of buildings. It has been funded by the Bourgogne district, ADEME and the LCA consulting office Cycleco. This software relies on the C-Build e-LICCO database (ecoinvent based) (20) and the e-LICCO method for environmental impact assessment of buildings (21). Several sets of indicators can be used, among which a set of twelve recommended environmental impact indicators. The latter are elaborated further in this paper.

Eco-Indicator99 (General)
Finally, the widely used Eco-Indicator99 method was applied to several building products and buildings. For a more detailed description of this method we refer to the methodological report (22). Following environmental impact categories are considered within this method: carcinogens, respiratory effects – inorganics, respiratory effects – organics, climate change, ionising radiation – human health, ozone layer depletion, ecotoxicity, acidification/eutrophication, land use, depletion of minerals and depletion of fossil fuels.

Relevance of the environmental impact categories
The results of the implementation of the SuFiQuaD method were analysed for one of the sixteen representative dwellings (detached house). Figure 1 shows the results for a selection of technical options (including both timber frame and solid structure alternatives). The relevance of the environmental impact categories in this project is determined based on the contribution (percentage) of the specific environmental impact category to the overall life cycle environmental impact (single score, expressed in monetary value). For the analysed dwelling this contribution is determined for 2714 alternatives, ranging in technical solutions and hence covering a wide range of building materials and energy performance levels. The minimum and maximum contribution of each impact category is calculated for this wide range of solutions. If at least one of the analysed building alternatives leads to a higher contribution of 10% for that specific impact category within the total single score of the building, it is assumed to be relevant. We however also identified the minimum contribution (i.e. what is the lowest contribution of that specific impact category for all building alternatives analysed). The difference between the minimum and maximum contribution of each impact category to the total score provides information on the decisive character of each indicator. It is assumed that if the difference is larger than 10%, the indicator has a decisive character.

The minimum and maximum contribution of each indicator is presented in Figure 4 based on the building life cycle results. Within this graphical representation the six key-pollutants have been integrated in the related impact categories (e.g. CO₂ equivalents are considered together with the impact category climate change) in order to allow for a better comparison with the results of the other methods. Following impact categories were identified as relevant based on the SuFiQuaD method: climate change, acidification, particulate matter formation and depletion of fossil fuels. Only climate change revealed to have a decisive character. A similar analysis was moreover made for a list of more than 300 building materials and products.
(cradle-to-gate), in order to exclude the often dominating contribution of operational energy. The results were slightly different as following impact categories revealed to be relevant: climate change, acidification, eutrophication, particulate matter formation, respiratory effects inorganics, ecotoxicity, land use and depletion of fossil fuels. All of these were decisive indicators.

The same approach was used to determine the relevance of the impact categories considered in the OVAM-MMG method. Based on the LCA results of 25 exterior walls following environmental impact categories revealed to be relevant: climate change, freshwater eutrophication, photochemical oxidant formation, particulate matter formation and land use (i.e. land occupation – forest). This is illustrated in Figure 2 for the exterior walls. Following impact categories moreover revealed to have a decisive character: climate change, particulate matter formation and land occupation – forest. The minimum and maximum contribution of the environmental impact categories is again summarised in Figure 4 based on the LCA of the building elements. A similar analysis of the building materials (cradle-to-gate) revealed that identical impact categories were identified as relevant.
The same detached dwelling which was analysed with the SuFiQuaD method was also analysed with the Eco-Indicator 99 method for a timber frame and solid structure variant. From this analysis, following impact categories were identified as relevant: carcinogens, respiratory effects inorganics, climate change and land use. The Eco-Indicator 99 method was moreover used to analyse a list of more than 300 building materials and products (cradle-to-gate). From this analysis, following environmental indicators were identified to be relevant: respiratory effects inorganics, climate change, ecotoxicity, land use, depletion of minerals and depletion of fossil fuels. The minimum and maximum contribution of each of the environmental impact for this cradle-to-gate impact is summarised in Figure 4. Because of the limited number of technical solutions analysed at the building level, the results presented in Figure 4 for Eco-Indicator 99 are those of the building product analyses. It is important to note that these hence differ from the results of the SuFiQuaD and OVAM:MMG method which are based on building LCA studies.

Within the e-LICCO project a different approach has been used to determine the relevant indicators and preferred life cycle impact assessment (LCIA) models (23). It is composed of the following steps:
Step 1: Categorisation of the midpoint environmental impacts listed in the ILCD handbook (19) and the ones provided by IMPACT 2002+ (24) and ReCiPe (25) in sub-damage categories within the three widely recognised damage categories (Ecosystem Quality, Human Health and Resources Depletion). Seven sub-damage categories have been defined: terrestrial pollution, aquatic pollution, human health, land use, materials and energetic resource depletion, water depletion and climate change. The objective of this categorisation is to group comparable indicators.

Step 2: As each sub-damage category was judged relevant, every sub-damage category needed to be covered. In consequence the sub-damage categories consisting of only one impact category were identified and the impact categories these consisted of were indicated as relevant. During this step following midpoint impacts were selected: climate change, mineral & fossil resource depletion, water depletion and land use. These are indicated in Figure 4 as full-coloured bars (no gradient).

Step 3: Based on a prior assessment of building case studies (i.e. based on energy and climate change impacts) within the e-LICCO project, a number of building related products and processes were identified as hot spots: manufacture of concrete-based products, wood-based products, metal-based products, photovoltaïc panels, heating processes and French electricity mix.

Step 4: Based on the environmental assessment of the identified hot spot products/processes using the midpoint impacts of both the IMPACT 2002+ method and the ReCiPe method; the contribution (percentage) of each midpoint related to the total score of the specific sub-damage category was determined. For this analysis the damage factors of the original methods were used. Figure 3 provides an example the results of the ReCiPe midpoint impacts contributing to the human health sub-damage category.
The importance of the midpoint impacts to the total sub-damage category is determined based on the contribution of the midpoint environmental impact score related to the total sub-damage score. If the contribution (C%) satisfies the following rule, the midpoint environmental impact is considered as important:

\[ C% > \frac{1}{n} \]

With \( n \) the number of midpoints contributing to the sub-damage category.

Step 5: Selection of relevant indicators. The indicator is considered as relevant if it has been found important for at least one of the hot spot processes analysed.

Based on this analysis, twelve environmental impact categories were identified as relevant: climate change, mineral and fossil fuel resource depletion, water depletion, terrestrial and aquatic acidification, terrestrial ecotoxicity, freshwater ecotoxicity, freshwater eutrophication, land use, ionizing radiation – human Health, respiratory inorganics, carcinogens and non-carcinogens.
Results

The analysis described in this paper can be seen as a first attempt to reduce the extended set of environmental impact categories to only the relevant ones for buildings and building related products. The results reveal following interesting issues. Firstly, our hypothesis that the set of indicators could be reduced by focusing only on the relevant ones proved to be correct (based on the approach suggested in this paper). We saw a reduction of the number of impact categories of about 56% for the SuFiQuaD project, 53% for the OVAM:MMG method, 29% for the e-LICCO project and 50% using the Eco-Indicator 99 method.

However, the analysis revealed that the procedure to define the relevant impact categories has clearly an influence on the results. The use of different impact assessment methods (and hence different ways of aggregating the impact categories) leads to a different set of relevant impact categories. Moreover, the a priori assumption of relevant sub-damage categories leads to a larger set of relevant environmental impact categories than when the determination of the relevance is based on share to the total impact score (without subdivision). The latter approach however does not guarantee that all sub-damage categories are identified as relevant.

The analytical results at the building level moreover differ from the ones at the building product/process level: different sets of relevant environmental impact categories are identified. The building scale analyses lead to lower contribution ranges of all impact categories other than climate change and particulate matter, due to the large share of the latter to the total environmental impact of the building. The set of relevant impact categories at the building scale (ranging from four to five relevant impact categories) is less extended than the set of relevant impact categories at the building product scale (ranging from six to twelve relevant impact categories). Because of the transition towards nearly zero energy buildings and the drastic reduction in operational energy, the set of relevant indicators based on building materials/products seems more relevant for new buildings. For existing buildings, the relevant impact categories determined based on the building scale analysis can however be seen as a priority.

Despite the differences noticed, three impact categories are identified as relevant based on all impact assessment methods used and based on analyses at both the building level and building product level: climate change, particulate matter formation and depletion of fossil fuels.

Conclusions and recommendations

The contribution analysis as presented in this paper provides insight in the importance/relevance of the different impact categories and hence contributes in interpreting the results of LCA studies of buildings and building related products.
That being said, there are many more approaches possible to determine the relevance of impact categories or to reduce the broad set of impact categories. The reduced set of indicators exposed in this article is still quite extended and hence weighting is still required in comparative analyses as contradictory indicators can still occur. We hence recommend to further investigate this issue in the coming future by confronting more LCA studies using different impact assessment methods and by using different techniques to determine the relevance.

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