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Comparison of life cycle assessment databases: A case study on building assessment

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ABSTRACT

Comparability of life cycle assessment (LCA) results based on different background data has long been debated. This is one of the main issues in building LCAs since buildings are complex products, which require multiple material data for the assessment. The objective of this study was to investigate numerical and methodological differences in existing databases related to building LCAs. The five databases selected were compared in terms of greenhouse gas (GHG) emission values in the material production phase of the three reference buildings, two wooden buildings with different frame types and a precast concrete framed building.

The results demonstrated that the databases show similar trends in the assessment results and the same order of magnitude differences between the reference buildings are shown by all the databases. It was also revealed that the numerical differences between the databases are quite large at some points and the differences originate from multiple data elements. The findings indicate the importance of the number of data and a clear statement of the bases of the values for comparative assessment. It would be more realistic to develop a reporting and communication system for LCAs rather than trying to unify the methodologies among the databases. An optimization of open information is significant for further development of LCA databases.

1. Introduction

In recent years, the desire to quantifying the environmental impact of human activities has increased more and more in order to help mitigate climate change. Various environmental certification systems are being established such as the Environmental Product Declaration (EPD) [1] and thanks to this trend, the quantifiable impact, such as carbon footprint or energy demand can, for instance, be seen on a product's label and in advertisements in daily life. This raises our awareness about environmental problems and leads competition in industry. Environmental life cycle assessment (LCA), which is a tool for assessing the environmental impact of products and services over their life cycles has been standardized and is now widely used. LCA supports industry or policymaker in making reasonable decisions concerning products, processes and policy strategies. Since LCA is a data-intensive method, the availability of adequate and reliable data is a fundamental issue for the assessment [2]. Normally it is not easy for LCA practitioners to access all primary data due to confidentiality and thus a number of diverse databases have been developed internationally to satisfy the demand for LCAs [3].

However the direct comparison of databases is debatable, because they consist of data collected from various sources and are based on different calculation methodologies according to their purpose. In principle, there are two different basic approaches to LCA, a process-based approach and an economic input–output (EIO) based approach. The process-based approach is the original method of LCA that computes the environmental input and output as it follows the actual process flow, whilst the EIO method is an inter-industry economic input–output analysis based on monetary transactions and resource consumption data [4,5]. Several researchers have conducted a comparison of LCA databases modelled by the two different approaches [6–8] and the results commonly indicate fundamental gaps in the modelling of data, which sometimes results in significant difference in the assessment result. But it has also been found that most of the values from the two approaches were the same order of magnitude [8]. Recently a hybrid method combining both approaches has been proposed and developed into a new LCA model [9].

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Peereboom et al. [2] conducted a comparison of six widely used European life cycle inventory (LCI) datasets to identify the data elements that accounted for major differences, and observed the influence of those elements on the result of an LCA conducted on the production of polyvinyl chloride. The main finding of Peereboom et al.'s research was that the specific data elements causing major numerical differences in the LCA results were geographical and temporal factors, technological representativeness, system boundaries, allocation methods and different category definitions for the inventories. The result indicated that different datasets would lead to different conclusions even in LCA studies on the same product. Therefore the authors recommended an appropriate and explicit description for the dataset, regular updating and high transparency and reliability of the dataset.

Chomkhamsri and Pelletierv [10] analysed methodological issues in existing environmental footprint standards and concluded that some important LCA modelling aspects are still inconsistent across the standards for product-related assessment. Reap et al. [11,12] specified methodological problems in LCAs based on a literature survey. In addition, Frischknecht [3] discussed the possibility of a set regional and global LCA databases based on the analysis of the currently used methodologies. The author concluded that one single ideal background database would not be realistic, and plurality in LCA with harmonization of some possible methodological aspects was recommended.

LCA has been also applied to the construction industry and much research has been done from several perspectives to understand the environmental profile of buildings and to investigate solutions to mitigate the impact over a building's life cycle [13–18]. However, comparability of results is also one of the main issues in building LCAs today [19]. Yokoo et al. [20] demonstrated the numerical differences in building LCA results arising from different database use. The numerical differences were shown clearly, although the number of building materials studied was limited and the reasons for the differences were not discussed. With this background, the objective of this study was to investigate numerical and methodological differences in existing databases related to building LCAs. Buildings are complex products consisting of many materials, so that appropriate LCA data for building materials is a prerequisite for the assessment. Thus building LCAs might be more sensitive to background data selection. Although little scientific attention has been paid to this question so far, it is important for comparable environmental assessment in practice.

Five LCA databases were compared by calculating greenhouse gas (GHG) emission values with their datasets in the material production phase (Cradle-to-gate) of three reference buildings. Numerical differences in the building assessment results arising from the different databases used were observed and reasons for the variations were investigated from the database's methodological background point of view. In addition, possible opportunities for the further development of LCA databases and the communication of assessment results are discussed from a practical perspective.

2. Materials and methods

2.1. Reference buildings

Three small box-shaped buildings ('box buildings') constructed at Otaniemi (Finland) were used as the reference buildings. The three box buildings had the same interior floor-area (10.14 m^2) and the same U-values (Wall and Floor = 0.1 W/m^2 K Roof = 0.09 W/m^2K). The first building, which was of light-weight timber construction ('Light weight box'), consisted of walls, floor, and roof elements framed with I-joists and LVL. The second building was of massive timber construction ('Massive box') and composed of cross-laminated timber (CLT) logs, forming the structural frame, and additional non-load bearing insulation elements framed with I-joists and LVL. The third building consisted of a precast concrete panel structure ('PC box'). Fig. 1 shows the basic composition of the buildings. These buildings were selected for the case study for the following reasons: 1) all detail information of the buildings was available, 2) the scale of the buildings was reasonable for the purpose of this study, 3) the buildings include the main construction materials, such as concrete, steel and several wood products, that suit the purpose of this study.

The volumes of the building components were converted to mass for the LCA calculations using the density of the materials. The total mass of each component used in the buildings are summarised in Table 1. Building service equipment, interior finishing, window and door were excluded from the calculation because they were the same in all buildings.

2.2. Compared life cycle assessment databases

The five databases compared in this study were: 'GaBi' (GaBi 6 professional and construction database), 'ecoinvent' (ecoinvent database V3.0), 'IBO' (the reference database published by the Austrian Institute for Healthy and Ecological Building GmbH), 'CFP' (the database for the carbon footprint of products Japan) and 'Synergia' (the datasets in SYNERGIA carbon footprint calculation tool developed by the Finnish Environment Institute) [21–25]. At the time the research was carried out, the latest versions of all the databases were used. GaBi and ecoinvent are commercial LCI databases, whilst IBO, CFP and Synergia are national open databases showing life cycle impact assessment (LCIA) results (CFP and Synergia show only GHG emission values) for the production phase of products. Brief descriptions of each of the databases are given below, whilst basic information about each is summarised in Table 2.

2.2.1. GaBi

The GaBi database is the largest internally consistent LCA database developed by PE international GmbH, Germany. The aim of this database is to provide unique and up-to-date life-cycle inventory (LCI) information to commercial users. This database comprises internationally collected primary LCI datasets from industry, associations and the public sector. The database is regularly updated based on industry resources, scientific knowledge, technical literature and internal patent information. The GaBi database is used as a reference database in Ökobau.dat, which forms the basis for the calculation of building LCAs in the context of the DGNB: German building certification system [26,27].

2.2.2. ecoinvent

The ecoinvent project was launched in late 2000 through a cooperation of several Swiss federal offices and research institutes of the ETH domain (Swiss Federal Institutes of Technology). The first database (version 1.01) was published in 2003 and the second version (v2.0) was released in 2007 based on an extension and revision of the first database. The latest version (v3.0) was released in May 2013. The aim of the ecoinvent project was to harmonize and update several public LCA databases developed by different institutes in Switzerland. In order to respond to increasing attention and the needs of LCA as well as demand for a high quality, reliable and consistent LCI, data has been collected over different industrial sectors. The ecoinvent database is one of the most well-known LCI databases worldwide [28,29].

2.2.3. IBO

The aim of the IBO database is to display the environmental performance of building materials and to help the development of