Comparison of life cycle assessment databases for building assessment

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Abstract: This study provides a detailed investigation of numerical differences in existing databases related to building LCAs. Selected six databases were compared in terms of greenhouse gas emission values in the material production phase of three reference buildings. 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. On the other hand, quite large numerical differences were found between the databases at some points. The reasons for the differences were discussed according to several 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. An optimization of open information is significant for further development of LCA databases.

Key words: Life cycle assessment, LCA databases, Greenhouse gas emission, Building, Cradle to Gate, Open information

1. Introduction

Life cycle assessment (LCA) includes several parameter values and scenarios (e.g. reference service life, functional unit, system boundary, background data, allocation of environmental impacts and benefits), which are defined by the goal and scope of the study [1]. Thus the results are case specific and comparability of those can be an issue in LCAs [2]. Especially the availability of adequate and reliable data is a fundamental issue for the comprehensive and comparable assessment, since LCA is a data-intensive method [3, 4]. Several researchers have conducted a comparison of LCA databases and the results commonly indicate fundamental gaps in the methodologies used, which sometimes result in significant differences in the assessment results [4-8]. Yokoo et al. [9] investigated 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. Buildings are complex products consisting of many materials, so that building LCAs might be more sensitive to background data selection.
The objective of this study was to investigate numerical and methodological differences in existing databases related to building LCAs. Six 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.

2. Methodology
2.1. Reference buildings

The studied objects were three small buildings with different frame materials, light weight timber frame (Building A), cross-laminated timber (CLT) frame (Building B) and precast reinforced concrete panel (Building C). The three buildings had the same interior floor area (10.14m²) and the same U-values (Wall and Floor=0.1W/m²K Roof=0.09W/m²K). 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.

<table>
<thead>
<tr>
<th>Building</th>
<th>Used mass (kg)</th>
<th>Building A</th>
<th>Building B</th>
<th>Building C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building A</td>
<td>2194</td>
<td>2036</td>
<td>813</td>
<td></td>
</tr>
<tr>
<td>Building B</td>
<td>0</td>
<td>3125</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Building C</td>
<td>0</td>
<td>196</td>
<td>61</td>
<td></td>
</tr>
</tbody>
</table>

2.2. Compared life cycle assessment databases

The six 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), ‘Synergia’ (the datasets in SYNERGIA carbon footprint calculation tool developed by the Finnish Environment Institute) and ‘ICE’ (Inventory of carbon & Energy, Version 2.0) [10-15]. At the time the research was carried out, the latest versions of all the databases were used.

2.3. **Statistical analysis**

The ecoinvent database was set as the reference database and the percentage of relative differences (PRD) in the result to the other databases were determined using equation 1. The choice of reference database does not imply a value judgement. This method can indicate a positive or negative difference compared with the reference database and facilitates a comparison as an index. For instance, PRDs of 200%, 100%, 50% and 0% mean that the results from the database is three times as large, twice as large, 1.5 times as large and equally as large as the result from the reference database, respectively. When PRD is negative, for instance -66.6% and -50%, the results from the database are, respectively, one third or one half of the results given by the reference database [4].

\[
PRD = \frac{(GHG_x - GHG_{ref})}{GHG_{ref}} \times 100 \quad (1)
\]

Where PRD is Percentage relative differences (%)
GHG\_x is GHG emission calculated by database x (kg CO\_2 -eq.)
GHG\_ref is GHG emission calculated by ecoinvent database (kg CO\_2 -eq.)

3. **Results and discussion**

3.1. **Comparison on building assessment level**

Figure 1 shows the GHG emission values for the material production phase of the reference buildings calculated with the six databases. All databases show the same trend in the GHG emission values, namely that the PC box displays the highest value and the light-weight box the lowest. This result is line with a previous study [9]. They compared concrete frame and steel frame building with three LCIA databases in terms of primary energy consumption and CO\_2 emission during the material production phase of the buildings. Each database naturally showed different numerical results, but the concrete building always exhibited higher value than the steel building.

Additionally, similar differences between the results of the three buildings are found in the case of each database, except for CFP, where the difference between the building C and the other two is smaller. The difference between the highest result and the lowest result in building A, B and C are 1.6, 1.5 and 1.4 times respectively. In the case of the wooden buildings (A and B), CFP yields the highest GHG emission values and Synergia the lowest value at all times. GaBi, ecoinvent and ICE show similar values in the case of the wooden buildings. IBO and ecoinvent yield relatively higher values to the building C, whilst the other three databases are quite similar.
3.2. Comparison on building component level

Figure 2 shows the assessment results of the reference buildings according to the main material groups. Wood and insulation products are the main GHG emitters in the wooden buildings, and insulation and concrete product are dominant in the building C. Large variation can be seen in the case of insulation material. On the other hand, the difference is relatively small in the wood products and concrete.

The effect of differences in the databases on the GHG emission values of the main building materials used was also examined. Figure 3 shows the PRD of the main materials used in the
reference buildings. As shown in the figure, major differences can be found in the values of wood fibre board and cellulose fibre insulation. This is the main reason for the disparity in the results of the wooden buildings. Although the differences in the values of the three main wood products: LVL, CLT and sawn timber, are relatively small, they also contribute to the differences in the building assessment results because of the large quantities used. On the other hand, the value for concrete does not differ very much between the databases, so that concrete only gives rise to small differences in the results despite the large quantity used. Thus the discrepancy in the results arising from the different databases observed in the building C originates mainly from variation in the unit value of EPS (Expanded polystyrene) and the reinforcing rods.

![Figure 3 Percentage of relative differences in the GHG emission value of main building components shown by the different databases (reference database is ecoinvent)](image)

### 3.3. Data elements contributing to the differences

The reasons for the differences illustrated above would originate in several data elements. At first, a gap between the databases with regard to the amount of construction materials data seems to be critical. In this study, for instance, there is a particular data shortage in the case of wood products in CFP and Synergia, and in insulation products in the case of CFP. As a result, several building materials had to be calculated with data from similar products. This data substitution could have a significant influence on the building assessment results. In particular the relatively high GHG emission values obtained using the CFP database in the case of the wooden buildings can mainly be explained by this aspect. Since there was no specific data for wood fibre board and cellulose fibre insulation in the CFP database, data for insulation board was used. This substitution, especially for cellulose fibre, would influence to the results significantly, since the unit value of insulation board in CFP is much larger than
the value of cellulose fibre in the other databases as displayed in figure 3. The substitution obviously lowers the accuracy of the assessment.

As reported in a previous study [4], technical and geographical representativeness of the material production process should be a significant data element. For instance, the energy profile of wood product manufacturing can be divided into two categories, electricity and thermal energy. Electricity is mainly used for machine operations. Thermal energy is used in the drying process (e.g. timber, veneer, and particles) and the pressing process in engineering wood products such as plywood and OSB. In general, the thermal energy for the drying and pressing processes account for approximately 70-90% of total energy consumption during wood product manufacturing [16, 17]. Thus the thermal energy resource could be regarded as the main factor influencing GHG emissions in the manufacturing process. Often biomass fuel is used alongside fossil-based fuels to generate this thermal energy, but the ratio between the two naturally varies depending on country, region and mills. On the other hand, production system and energy profile of the concrete production process seems to be rather unified [18, 19]. In fact, there is no biofuel used in concrete production according to the inventories of GaBi, ecoinvent and CFP. In other words, an absence of biofuel use in concrete production would cause little difference between the databases.

The electricity production mix differs depending on time and place. In addition, the reference year for the calculation varies from database to database and data by data. This variation naturally affects the environmental impact of the material production processes. Peereboom et al. [4] demonstrated that the PRD in the environmental impacts caused by different geographical representativeness of the electricity production data were approximately -30 to +50%, whilst different temporal representativeness yielded the PRD of less than 5%. Although electricity is not a major energy source in construction material production in many cases, minor differences between the databases would originate from this point.

There should also be an influence of other elements (e.g. primary data source, accuracy and aggregation level of the data, system boundary, allocation, impact assessment method). Those are not discussed in this paper due to lack of information and page limitation. The different LCA approaches, whether it be process-based or EIO-based, is not considered in this study neither.

4. Conclusion
Comparability of LCA results based on different background data is one of the main issues in building LCAs since buildings are complex products, which require multiple material data for the assessment. In order to investigate this question, six LCA databases were compared by conducting LCAs for the Cradle-to-Gate phase of three reference buildings.

This study demonstrated that the databases show similar trends in the assessment results and the same order of magnitude differences between the three buildings are shown by the all databases. The results 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 lead to the following general conclusions to further develop LCA databases: 1) to enrich the number of data, 2) transparent indication of the bases of the values used. For instance, IBO provides a relatively large number of data, but the bases are not explicitly stated. On the other hand, CFP includes few construction material data, but detailed background information is attached to each data. These two points should be compatible. Simple and transparent generic databases will lead to further popularization of LCAs at a practical level.

The findings of the current study are subject to the limitation of sample size. In addition, only GHG emission value for the Cradle-to-Gate phase of the buildings was discussed in this study. Thus future research could include other LCA databases, life cycle stages and environmental impact.

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