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Turning dynamic LCA principles into practice

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Abstract. The building and construction sector quantifies the environmental impacts of buildings using the Life Cycle Assessment (LCA) method. To put LCA into practice often simplified application of the LCA method is used, without considering timely aspects. Instead, the method dynamic LCA includes timely aspects, which are more complex in the modeling and thus difficult to apply. To investigate the consequences of using the dynamic LCA method, this study develops a tool that takes data available in a simple LCA tool that follows the standardized LCA method and calculates dynamic LCA results. The tool reimplements the calculation engine from the simple LCA tool and adds the more complex aspects of dynamic LCA afterward. Doing so makes it possible to add other complex methods to the original calculation engine to help investigate more complex methodological aspects in the future.

Keywords: sustainability, built environment, programming, tools

1. Introduction

Along with rising greenhouse gas (GHG) emissions, the focus on sustainable development has increased [1]. The building and construction sector is responsible for 39% of global energy-related GHG emissions, and of this, 11% is related to the production of building materials, and 28% is related to energy use in buildings [2]. For many years building regulations have focused on reducing energy use in buildings. As a result of the increasing focus on sustainability, material-related GHG emissions have gained focus.

Building Life Cycle Assessments (LCAs) according to the EN 15978 standard [3] account for emissions in the life cycle stages of *production of materials* (modules A1-3), *construction process, transport, and waste on the construction site* (modules A4 and A5), *use phase* (modules B1 -B7), *end of life phase* (modules C1-C4), and *potential for reuse and recycling beyond the end of life* (module D) [4], [5]. However, building LCAs are often complex and require much data on the building material flow and environmental impacts of materials. Therefore, it can be challenging to put LCA into practice.

1.1. Limitations of LCA methods and dynamic LCA

At the beginning of 2023, the Danish building authorities introduced a requirement for performing LCA of all new buildings [6]. Thus, simple LCA tools for the building and construction sector were developed to make adaptation easier.

Simple LCA tools are generally based on traditional LCA methods that follow the European Standard EN 15978 [3], [7]. However, to cope with uncertainties of the existing LCA method, new and more new and more complex methods are developed. A widely discussed uncertainty aspect in scientific literature is that traditional LCA methods are static and consider timely aspects poorly [8]–[14]. It is argued that the lack of temporal information in static LCA affects the accuracy of the LCA results. For example, it does not consider whether an emission is released at once or over time nor does it account for the effect of long-term carbon storage [8]–[14]. Especially for timber and other biobased products, which can store carbon through carbon sequestration, such timely aspects become increasingly relevant [13]–[15].

When constructing the life cycle inventory in static LCA, all emissions are accounted for in their respective life cycle stages. Then, when characterizing the emissions in the life cycle impact assessment phase, all emissions are characterized with constant characterization factors. In comparison, several different approaches to dynamic LCA exist. Sohn et al. split dynamic LCA into three categories, (1) dynamic process inventory, (2) dynamic system inventory, and (3) dynamic characterization [16]. Dynamic process inventory considers for example technology development by changing single-unit processes, whereas in dynamic system inventory technology development is incorporated by discrete changes in the processes [16]. In dynamic characterization, emissions are accounted for in the year they occur and characterized using varying and time-dependent characterization factors. By doing so, future emissions will have less impact on the atmosphere compared to emissions released now [8], [16].

An advantage of the static LCA method is that it has been applied in thousands of case studies, and its limitations and uncertainties are thoroughly investigated [17]–[21]. Likewise, dynamic LCA, along with other advanced methods, is typically challenged by not being tested on many building cases due to the complexity of the modelling. Thus, uncertainties remain about which design incentives the method generates. By testing the method on many different and diverse buildings such design incentives will become evident.

To deal with this issue, this study provides a tool for testing complex methods on large datasets available in simple LCA tools. The study takes the example of dynamic LCA, more specifically dynamic characterization, as the complex method and applies it to data available in the simple building LCA tool, LCAbyg.

2. Methods

An example of a simple LCA tool is the Danish tool, LCAbyg [22]. LCAbyg was developed by the Department of the Built Environment (BUILD) at Aalborg University and the Danish Housing and Planning Authority and targets the Danish building and construction sector. Since its release in 2015, LCAbyg has been used to assess the environmental impacts of an increasing number of building cases. The introduction of LCA requirements in the Danish Building Code in 2023 has led to an additional increase in LCAs of building cases carried out in LCAbyg. Today, data on over 200 building cases from the Danish building industry have been modelled in LCAbyg by BUILD alone.

Taking LCAbyg as starting point, we reimplemented the calculation engine from LCAbyg in the programming tool Python [23] using the Integrated Development Environment PyCharm [24]. This allowed us to develop and test the script rapidly and iteratively. Based on the reimplemented calculation engine from LCAbyg, we restructured our LCA inventory to fit the dynamic LCA principle. From this, we applied time delay factors to all emissions over the building reference service life to represent timely aspects in building LCAs. We use time delay factors from Resch et al. [10] that follow Equation 1.

$$(1) \qquad \tau(t) = 2 - e^{\frac{\ln 2}{T} t}$$

T is the time horizon for the Global Warming Potential (GWP) indicator ranging from 20 to 500 years and t is the time the emission occurs. Note that the time delay factors only apply to GWP and no other environmental indicators [10].

3. Results and discussion

To allow for easy adaptation of the dynamic LCA method, the tool uses a JSON file extracted from a building case in LCAbyg as input. The input JSON file has all data necessary to conduct an LCA, for example, material quantities for all life cycle stages (A1-3, A4, A5, B4, C3, and C4), product lifetimes, and product ids that refer to specific environmental data. In addition, the tool also inputs JSON files with environmental data and product ids on the material in the LCAbyg database gen_dk and relevant environmental product declarations (EPDs). From the JSON files, the tool extracts all data. It restructures the data into rows of building products (referred to as inventory items) for each life cycle stage and columns with material quantities and lifetimes for each inventory item.

To adhere to the dynamic LCA method, the tool adds another column with the year in the reference study period (RSP) where the inventory item is being used. This also represents the year that the emission occurs. For example, inventory items belonging to module A1-3, A4, and A5 are related to year 0 of the RSP, inventory items belonging to module B4 are related to the year where a replacement happens (depending on the product lifetime), and inventory items belonging to the end of life stage (module C3 and C4) are related to the final year of the RSP (e.g., year 50 if considering a 50 years RSP).

The process of extracting, restructuring, and recalculation the data is illustrated in Figure 1.

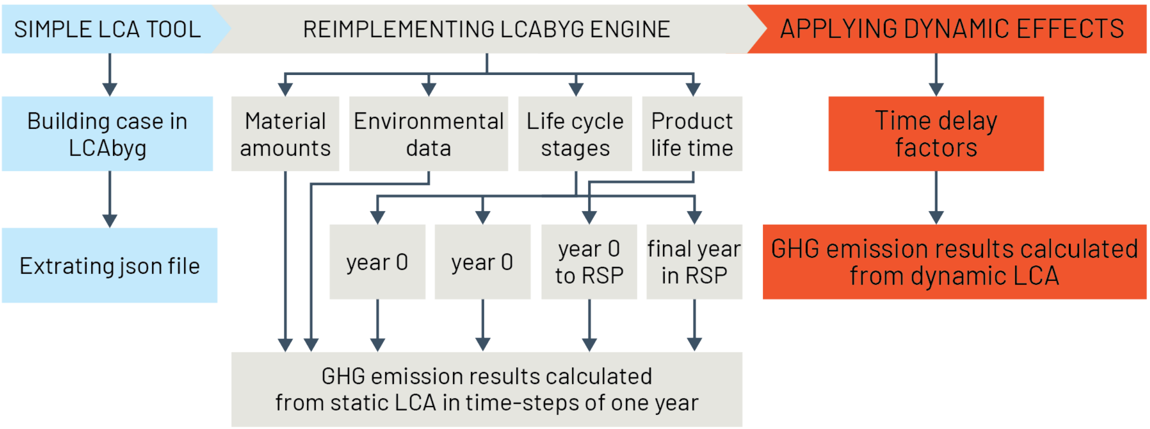

Figure 1. Dynamic LCA tool mapped in the different modelling steps

As a first step in the calculation, the tool merely calculates GHG emission results according to the static LCA method. This is done to enable a test and comparison of the calculation engine. From this, the tool adds time delay factors to all emissions depending on the time they occur. Emissions in year 0 are multiplied by a factor of 1 because current emissions are not discounted. In contrast, emissions in year 50 are multiplied by a factor of 0.58 and thus are discounted (according to the method proposed by [10] and presented in Figure 2). From this, the tool provides a results matrix with inventory items in the rows and the emissions for each year in the columns.

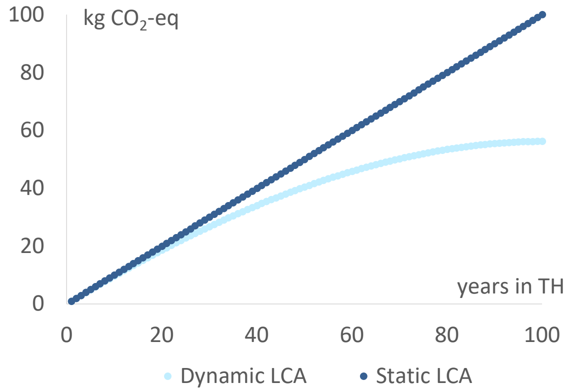

Figure 2. Example of static and dynamic LCA results when emitting 1 kg CO_2 each year in a 100 years time horizon (TH)

To ensure the quality of the tool, we tested it on 40 building cases. We compared the GHG emission results calculated in the tool against the GHG emission results provided by LCAbyg to make sure the reimplemented calculation engine gets the same results as LCAbyg. After, we checked the dynamic GHG emission results by drawing samples and manually calculating the results.

Figure 3 shows the results of one building case calculated using LCAbyg and the dynamic LCA tool. The building case is a wooden building with a simple design concept meaning that it is uninsulated, without any technical installations, no windows, and few interior walls. The result from the tool shows that the life cycle stage A1 to A3 is insignificant in this case. This is because the sequestered biogenic carbon in the wooden products is credited in A1 to A3 (according to the -1/+1 rule [25]) and the simple building construction cause only little impact. The dynamic LCA results show that future life cycle stages (B4, C3, and C4) have a lower impact than static LCA as these are discounted. We see that the end of life phase C3 experiences the largest reduction because this life cycle stage has a relatively significant impact due to the biogenic carbon in the wood being released by the end of life. Overall, the weight of the impacts is shifted towards life cycle stages early in the building life cycle (such as A1-3) while less weight is given to life cycle stages late in the building life cycle (such as C3 and C4) when applying the dynamic LCA method. Using the dynamic method to estimate the GWP of a building, therefore, pushes designers to focus on reducing early emissions related to the production of materials and the construction phase.

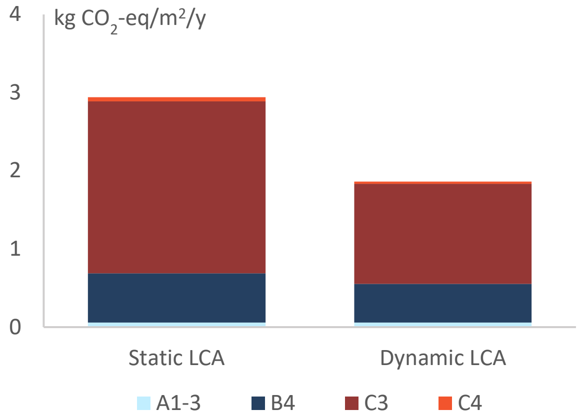

Figure 3. Static and dynamic LCA results for a wooden building case

Developing a tool that exploits the structure of the simple LCA tools and adds complexity to the method allowed us to test how timely aspects affect the LCA results of 40 building cases. Testing the dynamic LCA method on 40 cases and not just one case ensured increased data quality and helped evaluate the design incentives the method brings. Using the tool can help test the consequences of using complex methods like dynamic LCA on building cases and investigate how we represent the timely aspects of LCA. However, as this study merely focuses on tool development and provides an application example, we cannot elaborate on the consequences of using one method over the other. Another limitation of the tool is that it is restricted to building cases from LCAbyg and the dynamic LCA method, but since this tool reimplements the calculation engine of the tool LCAbyg and adds the dynamic LCA principle on top, it will be possible to add other complexities quite rapidly and thereby test the effect of other methodological aspects.

4. Conclusion

This study develops a tool that enables us to investigate complex methods on large datasets already available in the simple LCA tool, LCAbyg. The tool allows a rapid calculation of dynamic LCA results on actual building cases from LCAbyg, which makes it easy to compare the static LCA method to the dynamic LCA method concerning which design intensives the two methods entail. Ultimately, the tool provides an opportunity to include other complex methodological aspects of the static LCA method to test how different factors might affect building LCA results.

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