Should biogenic carbon be analysed separately in the calculation of the GWP indicator?

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Abstract. The life cycle assessment method is widely accepted for calculating the environmental impacts of buildings. However, the approaches used to translate greenhouse gas emissions to a global warming potential score are largely criticised. By following a static approach (known as 0/0) and a time-dependent approach (known as dynamic) in this paper, we assessed the environmental impacts of two buildings with structures made of reinforced concrete and wood, respectively. The relative difference between the results calculated with the 0/0 approach and the time-dependent approach were larger for the building with the wooden structure. A more detailed analysis identified biogenic carbon as the source that was most responsible for this difference in results. For this reason, biogenic carbon should be treated separately and must be calculated with the time-dependent approach. Meanwhile, the impacts from fossil energy sources should be calculated with the 0/0 approach.

1. Introduction

Buildings are responsible for 40% of greenhouse gas (GHG) emissions and constitute the biggest lever of impact reduction to prevent climate change [1]. For more than 30 years, scientists have been developing solutions to reduce the environmental performance of existing and new buildings [2]. Through a range of indicators, the international standardized method of life cycle assessment (LCA) has been used by scientists to calculate the impacts of new solutions and projects [3-4]. Global warming potential (GWP) is the indicator used to translate the effects of GHG emissions, processes related to building life cycle stages, and the burdens that contribute to climate change. The literature distinguishes three approaches useful for calculating the global warming potential indicator, which are differentiated by (i) types of GHG emissions included in the assessment of the GWP score, (ii) the time of release of gases in the atmosphere, and (iii) the time horizon of observed effects.

In the static 0/0 approach, the system boundaries to calculate the GWP score are limited to emissions from fossil energy sources, land use, and land use change (LULUC). The impacts from biogenic carbon emissions or uptakes are disregarded. The biogenic carbon uptake from the forest is released in the atmosphere when the timber building elements are incinerated at their end-of-life stage. Moreover, the GWP score is calculated under the hypothesis that the emissions from fossil energy sources and LULUC occur at time of building construction (t=0). The impacts are then calculated for a default time horizon (generally considered to be 20, 50, or 100 years) [5-6]. Meanwhile, the -1/+1 approach differs only from
the inclusion of biogenic carbon in the calculation of the GWP score. The uptake of biogenic carbon from the plants is considered with a negative value to the module of the production stage of the building. While the release of the biogenic carbon due to the burning of wooden elements is then counted in the end-of-life stage [7]. Despite these differences, the GWP score for an overall impact calculation is the same regardless of the approach used in the evaluations. As in the -1/+1 approach, the time-dependent approach considers all GHG emissions for the calculation of the GWP score. Furthermore, the calculated impacts of GHG emissions were considered when they were released into the atmosphere and the observed effects can be calculated for any specific time horizon [8].

Due to these differences, the GWP score of building projects can significantly vary in terms of the function of the approach used in the calculation. In a recent study [9], the relative gap between GWP scores were shown to be in the range of 30%. Besides, the literature is lacking studies analysing and identifying the sources of these differences.

Based on this knowledge gap and the need for a reliable impact calculation, the aim of this paper is to identify the sources responsible for these differences. To that end, this study analyses the environmental performances of two buildings with structures made of reinforced concrete and wood, respectively. The impacts are calculated using the 0/0 approach and the time-dependent approach and the relative differences between the results for all building life cycle stages were also calculated. Finally, the reasons for the gaps between the GWP scores were identified.

2. Method and Case Studies
The modular European norm EN-15978 [10] is used to calculate the environmental impacts of the various building life cycle stages. Within the system boundary of the study are included: the impacts of the production (A1-A3), construction (A4-A5), replacement (B4), and end-of-life (C1-C4) stages. Using a functional unit of square meter energy reference area per year of building reference study period, this study deals with the assessment of the global warming potential (GWP) indicator. The GWP score is calculated with the help of the 0/0 and time-dependent approaches. The differences between these two approaches are shown in Figure 1.

The assessment of the impacts through the 0/0 approach considers only the emissions released from fossil energy sources. For simplification purposes, in the calculation of the GWP score, we considered only the dioxide carbon (CO2), methane (CH4), nitrogen (N2O), and carbon monoxide (CO) emissions. These emissions have a contribution of more than 90% to the GWP score. According to this approach, the emissions related to the overall building life cycle stages were considered to be released at the building construction time (see 0/0 approach in Figure 1). A default time horizon equal to 100 years is calculated for the GWP score (GWP100).

On the other hand, the time-dependent approach includes in the calculation of the impacts both the emissions from fossil energy sources and biogenic carbons, which are released from the burning of biobased materials and the uptake of forest/plant regrowth. The biogenic carbon stored in the wood is calculated using the formula given in the European norm EN-16449 [11]. In addition, in this study, the wood losses for the production of timber building components are considered to be 10%. The uptake of biogenic carbon from the new forest planted during the contribution time and considered with a rotation time period of 100 year is linearly calculated. Furthermore, in the time-dependent approach for the calculation of the GWP score, the release of emissions (CO₂, CH₄, N₂O and CO) into the atmosphere was considered when they occurred. Finally, the observed effects can be calculated over any time horizon (see T-D approach in Figure 1).

Within the objective of this study, the GWP score of the 0/0 approach are calculated for a time horizon of 100 years. These impacts are then compared with the results obtained with the time-dependent approach for three scenarios: for a time-horizon of 100 years, long-term (in calculation, considered to be 1,000 years), and 100 years after the release of gases in accordance to the building life cycle stages. In order to calculate the GWP score with both methods, the ecoinvent database v.3.6 [12] was used and, for the time-dependent approach, the Dynamic Carbon Footprinter tool (DynCO2) [13] was adopted.
In this study, the environmental impacts of two buildings with different structural systems were assessed. With a 4,204 m² energy reference area (ERA), the building used for laboratory research [14] purposes is made with a reinforced concrete structure. Meanwhile, the residential building with a 1,004 m² [9] energy reference area (ERA) is made with a wooden structure. Both of them are new constructions situated in Graz, Austria and considered to have a reference study period of 50 years.

These buildings have been chosen as the most appropriate case studies. The case of the reinforced concrete structure constitutes materials and components produced through the use of fossil energy sources. Furthermore, several components have low lifespans requiring replacement during the reference study period of the building. For these reasons, the impacts of the building with the reinforced concrete structure were not influenced by the biogenic carbon emissions. On the other hand, the results for the GWP indicator are expected to be perturbed only by the time when the emissions released into the atmosphere are considered in the calculation.

The second building has a large quantity of wood components, making it the best scenario to analyse the influence of biogenic carbon emissions in the reliability value of the GWP indicator. In addition, all materials and components have equal lifespans as the building. Through this case, it will also be possible to analyse the influence of time when the biogenic carbon emissions released in the atmosphere are considered in the calculation on the reliability of the GWP score.

![Figure 1. 0/0 and time-dependent approach (fos=fossil, bio=biogenic, A1-A5, B4, and C1-C4 are respectively the building life cycle of production and construction, replacement, and end-of-life).](image)

3. Results
The Global Warming Potential (GWP) indicators of the two buildings with the reinforced concrete structure and wooden structure assessed with the 0/0 and time-dependent (T-D) approaches are presented in Figure 2. This figure also shows the relative differences (ratio of differences between the
results over those obtained with the T-D approach) of results obtained with both approaches. Calculated with the 0/0 approach for a time horizon of 100 years, the building with the reinforced concrete structure has impacts equal to 11.9 kg CO\textsubscript{2}e/m\textsuperscript{2}ERA/yr. At the same observed time horizon, the impacts of this building calculated with T-D approach are equal to 10.7 kg CO\textsubscript{2}e/m\textsuperscript{2}ERA/yr. For the long-time horizon, the GWP indicator is equal to 11.7 kg CO\textsubscript{2}e/m\textsuperscript{2}ERA/yr. The relative differences between these results are respectively 10% and 1.5%. In conclusion, the release time of gases is a parameter with a significant difference for the short-observed time horizon and almost insignificant for the long-observed time horizon. This preliminary conclusion can be stated as valid in the case of building components produced using fossil energy sources.

Calculated with the 0/0 approach, the building with the wooden structure has a GWP score equal to 5.8 CO\textsubscript{2}e/m\textsuperscript{2}ERA/yr. The impacts for an observed time horizon of 100 years and the long-observed time period were calculated using the T-D approach are equal to 9.4 kg CO\textsubscript{2}e/m\textsuperscript{2}ERA/yr and 12 kg CO\textsubscript{2}e/m\textsuperscript{2}ERA/yr, respectively. The relative differences equal to 38% and 50% are significantly higher compared to those obtained for the building with the reinforced concrete structure. The unexpected result is that the differences are larger for the increased observed time horizon. In addition, the impacts calculated using the T-D approach were higher than those calculated using the 0/0 approach. These significant relative differences can mostly be attributed to the impacts of biogenic carbon.

For the building with the reinforced concrete structure, the sources of the gap between the results calculated with the different approaches were the replacement (B4) and end-of-life stages (C1-C4). These results show that the time the gases were released into the atmosphere has an influence on the reliability value of the GWP score. However, it deserves to be highlighted that the impacts calculated with the 0/0 approach are always overestimated. Besides, for the long-term time horizon, the difference between the results assessed with both approaches is insignificant. On the other hand, the calculation of impacts with the T-D approach is complex and time consuming. For practical reasons, the use of the 0/0 approach for the calculation of the GWP score for fossil energy sources is more advantageous than the T-D approach.

Similar results were obtained for the life cycle stages (A1-A5 and C1-C4) of the building with the wooden structure. However, the results for the stages with biogenic carbon sources are significantly different. As stated above, the impacts calculated with the 0/0 approach considered only the gases from fossil energy sources. These limitations have a significant influence on the reliability of the GWP score.
when biobased materials with high biogenic carbon content are employed in the building. As shown in Figure 3, the impacts from the burning of biobased materials were present at the production stage (A1-A4) and related to the losses for the production of timber elements. At the end-of-life stage (C1-C4) of the building, the components are incinerated for energy recovery purposes. On the other hand, the uptake of biogenic carbon gases from the regrowth of the forest must also be considered. In the present case study, the wood employed in the building is considered to be incinerated before the full growth of the new forest. This is the reason for explaining the highest value of impacts from the burning of wood materials compared to the biogenic carbon uptake from the new forest. Furthermore, the significant influence on the reliability of the GWP score of observed time effect in the case of biogenic carbon deserves to be highlighted. This influence is observed by comparing the impacts of the B1 and C1-C4 stages calculated with the T-D approach for 100 years and the long-term observed time effect. Based on the results obtained for both buildings, we can conclude that the biogenic carbon should be treated separately and the GWP score should be calculated with the help of the T-D approach.

![Figure 3. Overview of the identified strategies and the GHG emissions reduction potentials.](image)

### 4. Conclusion

In this study, we calculated the environmental impacts of two building with a reinforced concrete and a wood structural system, respectively. Results for the global warming potential (GWP) indicator were calculated using the 0/0 approach and the time-dependent approach. For the building with the reinforced concrete structure, the relative difference of the GWP score calculated with both approaches was equal to 10.5% and 1.5% for the 100-year time horizon and the long-observed time horizon, respectively. These gaps were associated to the time when the emissions of gases were considered for the calculation of the GWP score. For the building with the wooden structure, the relative difference was 38% and 50%, respectively. A more detailed analysis highlighted the biogenic carbon as responsible for the large gap between the results for the building with the wooden structure.

Finally, we concluded that treating the impacts of biogenic carbon separately decreases the gaps between the results. Although the time-dependent approach presents reliable results, due to its complexity and time consumption, it is not recommended to be used for the calculation of the impacts of fossil energy sources. Due to simplicity, the 0/0 approach is more advantageous since the results calculated from this method present a small range of uncertainties and always overestimate the impacts. On the other hand, the impacts arising from biogenic carbon should be calculated with the help of the time-dependent approach and the results should be presented in a separate indicator.
In perspective we recommend deepening the analysis for the identification of other sources of uncertainties between the approaches used for the calculation of environmental impacts of the buildings.

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