Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment

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Key words:

carbon footprint
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Summary

A growing tendency in policy making and carbon footprint estimation gives value to temporary carbon storage in biomass products or to delayed greenhouse gas (GHG) emissions. Some life cycle-based methods, such as the British publicly available specification (PAS) 2050 or the recently published European Commission's *International Reference Life Cycle Data System (ILCD) Handbook*, address this issue. This article shows the importance of consistent consideration of biogenic carbon and timing of GHG emissions in life cycle assessment (LCA) and carbon footprint analysis. We use a fictitious case study assessing the life cycle of a wooden chair for four end-of-life scenarios to compare different approaches: traditional LCA with and without consideration of biogenic carbon, the PAS 2050 and *ILCD Handbook* methods, and a dynamic LCA approach. Reliable results require accounting for the timing of every GHG emission, including biogenic carbon flows, as soon as a benefit is given for temporarily storing carbon or delaying GHG emissions. The conclusions of a comparative LCA can change depending on the time horizon chosen for the analysis. The dynamic LCA approach allows for a consistent assessment of the impact, through time, of all GHG emissions (positive) and sequestration (negative). The dynamic LCA is also a valuable approach for decision makers who have to understand the sensitivity of the conclusions to the chosen time horizon.

Introduction

Over the last few years there has been growing concern about the lack of consideration for temporal aspects of greenhouse gas (GHG) emissions in life cycle assessment (LCA) and carbon footprint analysis. Two different factors explain this concern: (1) an increasing will in policies and carbon footprint methods to give value to temporary carbon storage, and (2) the inconsistency in time frames when assessing the impact of GHG emissions, even when adopting global warming potentials (GWPs) with a fixed time horizon. Another topical issue regarding the assessment of GHG emissions is the consideration of biogenic carbon, for which there is no consensus among different methods. Using a fictitious case study comparing different approaches, the objective of this article is to show that the results of a life cycle GHG assessment are sensitive to the assumptions regarding the timing of emissions and the consideration of biogenic carbon, and that dynamic LCA is the preferred approach to address these issues consistently.

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Table 3 Comparison of the results obtained with five different approaches for 100- and 500- year time horizons (in kg CO_2-eq)

	100 years				*500 years*			
Method	*Incineration*	*Landfill*	*Refurbishment*	*Energy recovery*	*Incineration*	*Landfill*	*Refurbishment*	*Energy recovery*
LCA_{dyn}	5.6	1.2	**−3.0**	1.8	−1.2	**−16.3**	−8.6	−12.3
$LCA_{without}$	2.3	5.5	2.7	**−10.3**	2.2	2.9	1.5	**−10.2**
LCA_{with}	−2.6	**−17.5**	−8.6	−15.1	−2.7	**−20.0**	−10.0	−15.1
$LCA_{PAS2050}$	−6.9	**−13.5**	−11.3	−4.1	N/A	N/A	N/A	N/A
LCA_{ILCD}	−11.8	**−20.2**	−14.7	−17.9	N/A	N/A	N/A	N/A

Notes: LCA categories refer to dynamic LCA, traditional LCA without and with biogenic CO_2, PAS 2050, and the *ILCD Handbook* method, respectively. kg CO_2-eq = kilograms carbon dioxide equivalent.

The PAS 2050 specification ($LCA_{PAS2050}$) does not assess biogenic CO_2 emissions, but instead assumes that an equivalent amount of CO_2 has been sequestered in the recent past. A credit, represented by a negative emission, is given for any delayed emission (fossil or biogenic). This credit is proportional to the fraction of the 100-year time period following a product's formation during which its emissions will be in the atmosphere. The results show that, according to the PAS 2050, the landfill scenario is better than the others because of permanent carbon sequestration. The landfill scenario is also preferred according to the *ILCD Handbook* method (LCA_{ILCD}). The major difference between these two is that the ILCD method considers biogenic CO_2 emissions in the calculations, while the PAS 2050 does not.

The three major differences between the PAS 2050 and *ILCD Handbook* on the one hand and dynamic LCA on the other hand are (1) the choice of a time horizon, which is fixed at 100 years for the PAS 2050 and *ILCD Handbook*, but remains adaptable for the dynamic LCA approach; (2) the temporal distribution of the sequestration, which is only accounted for in the dynamic LCA approach; and (3) the individual assessment of delayed emissions of all GHGs other than CO_2 using so-called dynamic characterization factors; in the PAS 2050 and *ILCD Handbook* a proxy is used by multiplying each GHG by its respective GWP_{100} before calculating the credit. The results in table 3 show that these differences can lead to opposite conclusions. Indeed, the best scenario according to both carbon footprint methods (PAS 2050 and ILCD) is not the same as that identified when using the dynamic LCA approach. Because it assesses the specific radiative forcing impact of every GHG flow (positive and negative emissions of any type of GHG from fossil and biogenic sources) on a consistent time frame, and because it allows decision makers analyzing the sensitivity of the conclusions to choose a time horizon, dynamic LCA is considered a preferable approach.

When to Account for the Sequestration of Carbon in Growing Trees

The results of the first case study show that the choice to consider biogenic carbon or its temporal distribution can significantly change the LCA results. Using dynamic LCA for the assessment of products containing biogenic carbon also raises the issue of temporal boundaries. The dynamic LCA conducted on one chair built at year 1 and burned at its end of life 50 years later shows very different results depending on whether the sequestration is assumed to occur before or after the chair is built (see figure 2).

For a time horizon of 100 years, the "before" scenario has a cumulative radiative forcing benefit (negative value) three times higher than the impact (positive value) of the "after" scenario. For a time horizon of 500 years, both scenarios have a negative cumulative radiative forcing; the "before" scenario has 4.3 times more forcing than the "after" scenario.

The methods that have been proposed to-date to account for temporary carbon storage (PAS 2050 and *ILCD Handbook*) do not consider the timing of the sequestration. The end-of-life biogenic CO_2 emissions have a zero impact (emissions − sequestration = 0), and a credit is given for storage related to the ratio of the storage time over the chosen time horizon. This gives a net negative impact. The results of the dynamic LCA show that the impact is very sensitive to the dynamics of the carbon sequestration (carbon balance curve) and to its timing (before or after the product is manufactured).

For the "after" scenario of this case study, it takes 270 years after the chair is built before the cumulative radiative forcing becomes negative, and it does so because we consider that a part of the sequestered carbon is permanently held in the soil. In the case where no carbon is sequestered in the soil, the impact would never become negative.

Because these results are very different for the "before" and "after" scenarios, the setting of an initial temporal boundary is both critical and informed by two opposing viewpoints. Choosing the "before" scenario means that one assumed the trees were grown to be used as a raw material. Choosing the "after" scenario means that one considers that nature provides some resources that can be used as raw materials; because wood is a renewable resource, a tree can be planted to replace the one that is cut.

Conclusion

There is currently no consensus regarding how to treat biogenic CO_2 in LCA. In this article we showed that not considering biogenic CO_2 can lead to biased conclusions. If a fraction of the biogenic carbon is assumed to be sequestered

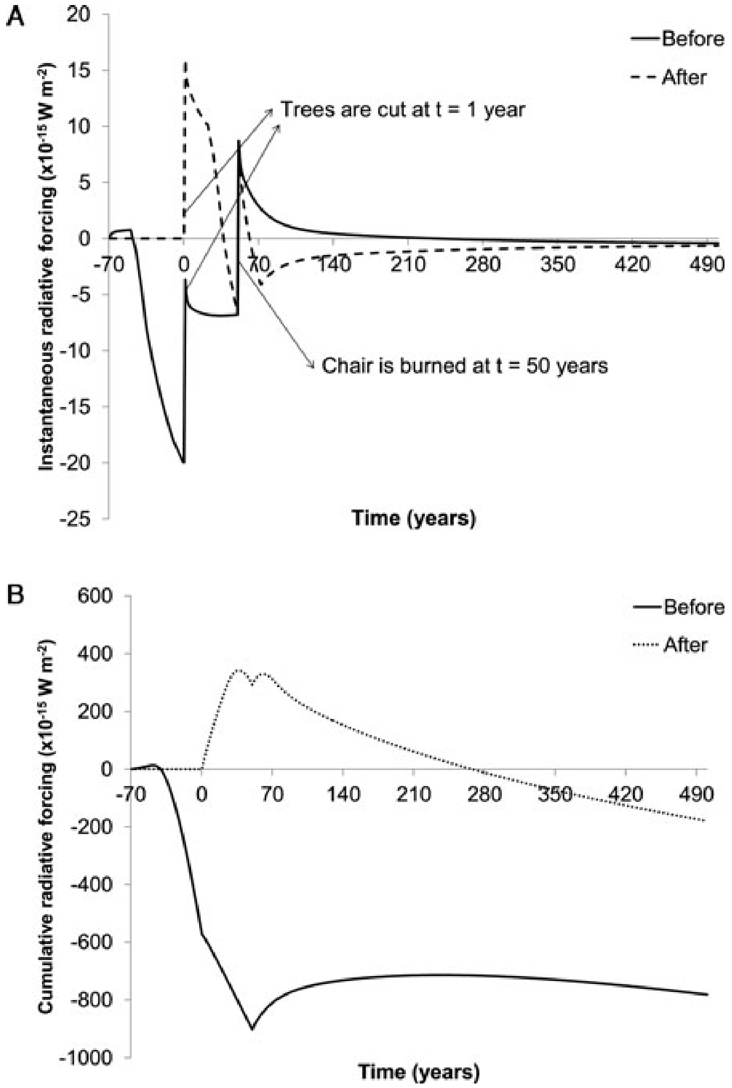

Figure 2 Instantaneous (a) and cumulative (b) radiative forcing determined using dynamic LCA, caused by one wooden chair for the incineration scenario with a sensitivity analysis done based on the timing of the sequestration (i.e., whether it occurs before or after the chair is built). W = watts.

permanently, as was the case for the carbon sequestered in the soil of the boreal forest or for 96.8% of the landfilled carbon, then the amount of biogenic carbon entering the product system is not equal to the amount leaving the system, which means that biogenic CO_2 emissions cannot be considered neutral. Also, as soon as a benefit is given for temporarily storing carbon, even if the total amount of biogenic carbon entering the product system is equal to the amount leaving the system, then it becomes important to account for the timing of every CO_2 flow that occurs in the life cycle inventory. Methodological inconsistencies otherwise lead to unreliable results. The dynamic LCA approach allows the consistent assessment of the impact, through time, of every GHG emission and sequestration, avoiding the necessity to artificially tag carbon flows as biogenic or fossil in origin.

Dynamic LCA also allows sensitivity testing of the results by time horizon. On an infinite time basis, there is no benefit to temporarily storing carbon or to delaying GHG emissions. Giving value to temporary climate mitigation is made possible by defining a time horizon beyond which we do not consider impacts, or by discounting, similar to what is done in economic decision making (Levasseur et al. 2012a).

The use of a discount rate to increase the importance of short-term emissions is still a controversial issue (Hellweg et al. 2003; Nordhaus 2007; O'Hare et al. 2009; Stern 2007), and is more a policy-based question than a scientific one, as is the choice of time horizon (Fearnside 2002; Moura-Costa and Wilson 2000). Given the debate concerning discounting and the fact that carbon footprint calculation methods do not use this type of time preference, we have decided to present the results without any discounting. However, it is possible for decision makers to apply a discount rate to annual dynamic LCA results like those presented in figure 1.

Choosing a finite time horizon for results analysis also provides a weight to time itself, and is a particular case (or a hidden