A comparison of LCA approaches accounting for CO_2 emission and sink of forestry products

The case of timber as a construction material

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Abstract

Life cycle Assessment **(LCA)** is a decision-making support tool used to assess the environmental impact of product systems. Due to the increasing awareness towards the necessity of mitigation and adaptation to climate change impact, LCA has been extensively used for assessing the environmental impact/benefit of substituting conventional materials with wood products[2]. This study compares different existing LCA methodological approaches to include forest carbon cycle in LCA. The results show a strong dependency of the LCA outcome on the methodological approaches adopted. The findings suggest an accurate forest model that includes: indirect Land Use Change effects, the timing of emissions/sink of carbon and a comprehensive forest carbon pool.

Introduction

Forests play a key dual role, both sequestering carbon from the atmosphere and emitting carbon due to forest residues degradation after harvesting or thinning activities[3]. In LCA, biomass from sustainably grown forests tend to be considered carbon neutral as the carbon released during combustion is assumed to be re-sequestered in the growing biomass[4]. Nevertheless carbon neutrality does not mean that the process implies climate neutrality: if during the time in between carbon release and sequestration, the carbon stays in the atmosphere, a warming effect is achieved and the impact can be remarkable. Whether and how much carbon is released in the atmosphere, depends on the use of the biomass and its source: if used for long-lived products, if used for substitution of other materials (fossil fuels, construction material) or if a change in the forest carbon stock occurs (stems, branches, roots, litter, soil), and the time considered for the biomass re-growth.

Aim

The objective of this study is to model the forest carbon cycle and compare the following four methodological approaches selected from an extensive literature review:

- Indirect Land Use Change **(iLUC)** modelling
- Approach adopted to express the climate indicator, to evaluate the climate Life Cycle Impact Assessment **(LCIA)** of the process
- Time horizon **(TH)** considered
- Forest carbon pool accounted (whole carbon pool, only above ground carbon or only carbon in stem)

The outcome is expected to answer the following research question:

- *How to include forest carbon cycle in Life Cycle Assessment of forestry products?*

by answering the sub-research questions:

1. *What would be a good compromise between an accurate LCA model and an acceptable degree of complexity?*
2. *Does the carbon stored in long-lived products (e.g. timber for construction materials) modify the environmental impact of falling a tree?*

Case

A case study is chosen to ensure the comparability of the tested approaches. Due to timber's increasing relevance as a sustainable construction material, the case study selected was the production of 1 m[3] of spruce wood for construction material, from a boreal forest located in southern Sweden.

It is assumed that the wood used in constructions has a lifetime of 100 years, after which the wood is incinerated.

Materials and Methods

Functional unit

1 m[3] of spruce wood used for construction material.

Reference flow

The area considered for the forest C balance is 1 hectare of land, with a time frame unit of 1 year. The Net Primary Production (NPP_0) is the reference flow, measured in tons of carbon.

Co-product allocation and system expansion

This study utilizes a consequential LCA **(CLCA)** approach to deal with co-product allocation through system expansion: the studied product system is expanded to include the processes displaced by the co-product. The identification of the displaced product is based on market mechanism and market data. Once the displaced product and its production process are identified, these are assumed substituted by the co-product. The identification of the substituted product in CLCA follows market mechanism instead of average data[5].

Life Cycle impact Assessment (LCIA)

The Global Warming Potential **(GWP)** is used for LCIA. Two approaches of GWP are tested: a static approach, not accounting for the timing of GHG emissions and sink, and a dynamic approach, weighting the GHG emissions for a time dependent factor.

Modelling assumptions testing plan

For each methodological approach, a number of different options were tested and compared against each other. The options tested for each of the methodological approaches are shown in the Table1. Table 2 shows the modelling assumptions testing plan. The blue variable are kept constant. The other colours underline three different groups of tests. The results are compared against each others and analysed according to these three groups.

Table 1

A) LAND USE MODEL
1. Indirect land use change modeling (ILUC)
2. No-iLUC modeling
B) CLIMATE INDICATOR
1. Dynamic approach: CO_2 based on GWP
2. Static approach: GWP set to a constant, 1 per year<=TH; GWP = 0 per year>TH
C) TIME HORIZON
1. 100 years
2. 20 years
3. 500 years
4. 1000 years
D) FORES C STOCK MODELLING
1. All terrestrial carbon stock
2. Only C stock in Stem wood
3. Above Ground Carbon

Table 2

LCAs n.	LAND USE MODEL	CLIMATE INDICATOR	TIME HORIZON	FORES C STOCK MODELING
1	A1	B1	C1	D1
2	A2	"	"	"
3	A1	B1(with GWP-20)	C2	"
4	"	B1(with GWP-500)	C3	"
5	"	B2	C1	"
6	"	B1(with GWP-20)	C2	"
7	"	B1(with GWP-500)	C3	"
8	"	B2	C4	"
9	"	B1	C1	D2
10	"	"	"	D3

Forest Biogenic Carbon Cycle

Forest biomass is divided in above ground **(AG)** and below ground **(BG)**. Each is then further divided in sub-categories. Figure 1 shows how all these categories function as both inputs and outputs of the forest carbon cycle. Figure 2 shows how the thinning procedure modifies the trend of the C stored in the forest during the rotation time, specifically in the total amount of harvested stem wood and harvested wood residues in the forest. In Figure 2 the three thinning modeled coincide with a drop of the carbon stored in stem and residues, as the thinned stems and residues are assumed harvested. It is assumed that the wood already present in the market immediately satisfies the demand of wood; the wood harvested today obviously grew in the previously 70 years (assuming a rotation time of 70 years). The red line in Figure 2 outlines the time window considered in this study for which the carbon cycle is accounted.

Figure 1

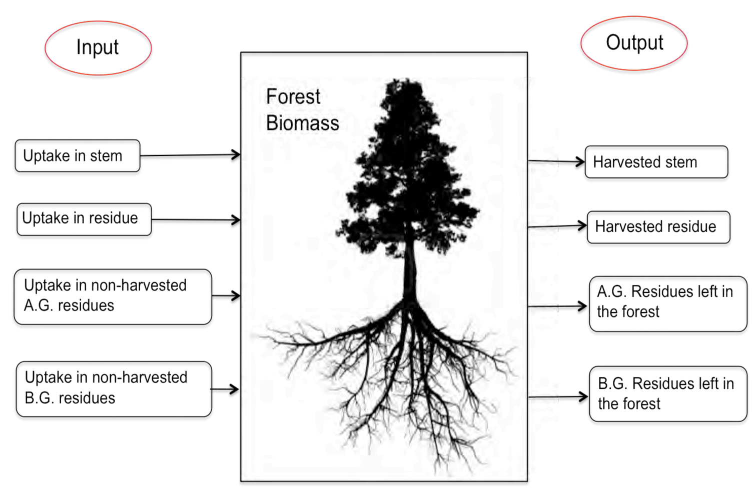


Figure 2

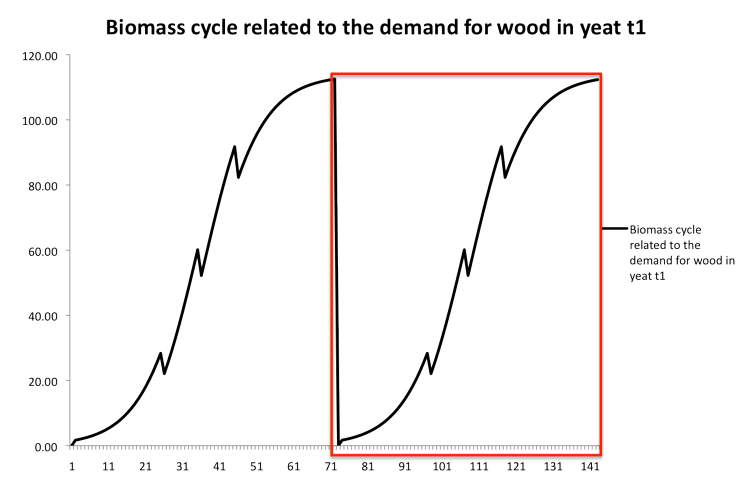


Figure 3

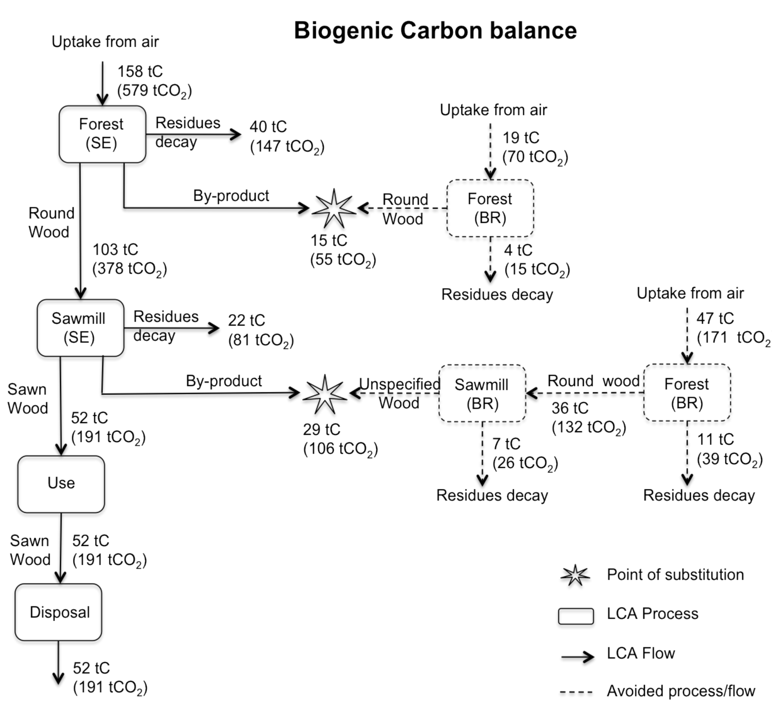


Figure 3 shows the biogenic carbon balance including the product system. The system is expanded to the avoided product due to product substitution. The avoided product identified according to a CLCA approach, is pulp and paper wood from an eucalyptus plantation in Brazil. The methodology adopted for the model of the forest carbon cycle in the spruce plantation has been used to model the eucalyptus plantation. All the processes are in balance.

Results and Discussion

Figure 4 shows the outcome of the ten scenarios modeled according to the testing plan (Table 2). The figure shows the net GHG contribution in CO_2 equivalent emissions (positive value) or uptake (negative value) for each process resulting from the 10 scenarios modeled.

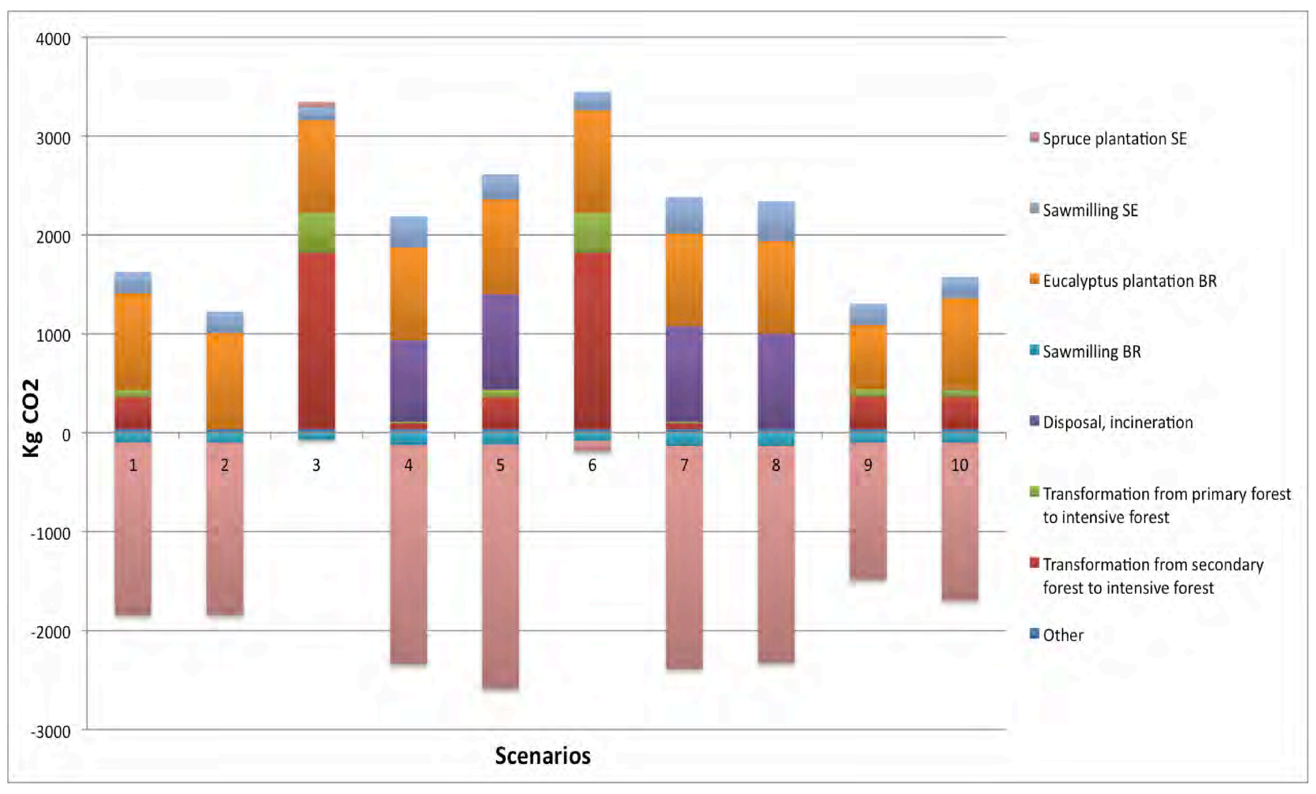
iLUC model

The choice of modelling the iLUC effect (scenario 2) increases the net final GHG emitted compared to the scenario where iLUC is not included (scenario 2). This suggests that in general, the effect of indirect land use change cannot be disregarded. CO_2 emissions from iLUC are generated both from transformation of primary forest to intensive forest and from secondary forest to intensive forest (red and green colors in Figure 4): primary forests (an old-growth forest) have a higher concentration of C in soil, since the soil C decreases by increasing the number of harvesting.

Climate indicator and TH

The results for the GWP20, both with static and dynamic approach (scenario 3 and 6), have a very different profile. The combined effect of iLUC and a 20 year TH leads to a very small contribution of the spruce plantation in C uptake. Albeit only with a small amount, in scenario 3 the spruce plantation contributes for a net positive factor (the net contribution after 25 years is a net emission of GHG). The eucalyptus plantation contributes with a net emission of CO_2 to the C balance because the Eucalyptus plantation is an avoided process: consequently, emissions from this process are accounted as avoided emissions. CO_2 sequestration from an avoided process is accounted as avoided sequestration, which entails a net emission of carbon. This is valid also for the results of the other tested scenarios. Similarly, the sawmilling process is a net CO_2 emitter and the emissions from the Swedish sawmilling process are visible as a positive value. The emission from the avoided process Eucalyptus sawmilling, are instead negative, as they are avoided emissions. A static approach (constant GWP) overestimates the effect of GHG emission uptake/release, since it does not weight them for a time dependent factor.

Figure 4



Using a static or dynamic approach alters the final impact of the system: Scenario 5 shows the highest value of GHG sequestration from the spruce plantation, also higher than scenario one, despite the TH is the same (100 years), since a static approach is used in the LCIA for the climate indicator, where the emissions/uptake of C are accounted independently on the time factor. GHG sequestered in the first year or at the end of the rotation time are in this case considered in the same way. The climate indicator affects the model also with regard to the disposal process.

Note that if a dynamic GWP500 is assumed (scenario 4 and 7) the iLUC model might be ignored because its contribution in terms of GHG equivalent in this case is little.

Forest carbon pool model

A comparison of scenario 1, 9 and 10 shows how also different forest carbon pool influence the LCA outcome. Scenario 9 results in a higher CO_2 uptake than scenario 10, despite the former accounting for carbon in the stem and the latter for the AG biomass. Among the last group of assumptions tested, the most reliable results were drawn from the first scenario.

Take-home

The results suggest that in order to include the carbon cycle in LCA, it is necessary to:

- Account for the effect of the iLUC model, especially for a short or medium-value Time Horizon
- Adopt a dynamic LCIA indicator, accounting for the timing of emission and sink
- Include both above and below ground carbon stock.

The results underline that in order to reach a reliable conclusion a certain degree of complexity of the model is required, keeping into account several aspects affecting both the LCI and LCIA phase. Increasing the accuracy of the model improves its conformity to the reality and allows for more reliable results to be reached. Nevertheless, the answer depends on the purpose of the study including its goal and scope. Some of the choices might be neglected in specific conditions with limited consequences on the final result.

The use of wood in long-lived product does alleviate the environmental impact of falling a tree, provided that new trees are re-planted and the by-products of the system are used in the pulp and paper industry. The process may even be beneficial for the environment, contributing to negative GWP, because the GWP from uptake is larger than for emissions. The advantages are only substantial after a period of time longer than 20 years.

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