Construction and Building Materials 125 (2016) 219–226

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Exploring the climate impact effects of increased use of bio-based materials in buildings

Diego Peñaloza [a,b,*], Martin Erlandsson [b,c], Andreas Falk [b]

[a] SP Technical Research Institute of Sweden, Drottning Kristinas väg 67, 114 86 Stockholm, Sweden
[b] KTH Royal Institute of Technology, Brinellvägen 23, 114 86 Stockholm, Sweden
[c] IVL Swedish Environmental Research Institute, Valhallavägen 81, 100 31 Stockholm, Sweden

HIGHLIGHTS

- Three building designs with increasing biobased material content were modelled and analysed using LCA.
- Dynamic LCA was applied to account for biogenic carbon sequestration, storage and emissions.
- Increasing biobased content reduces climate impact even if biogenic exchanges are assessed.
- Time horizon, timing of forest growth and end-of-life recycling are key assumptions.
- Time horizons lower than 100 years are not enough to capture properly climate impacts from buildings.

ARTICLE INFO

Article history:
Received 4 November 2015
Received in revised form 15 July 2016
Accepted 10 August 2016
Available online 17 August 2016

Keywords:
Life Cycle Assessment
Dynamic LCA
Wood construction
Biogenic carbon dioxide
Climate impact assessment

ABSTRACT

Whenever Life Cycle Assessment (LCA) is used to assess the climate impact of buildings, those with high content of biobased materials result with the lowest impact. Traditional approaches to LCA fail to capture aspects such as biogenic carbon exchanges, their timing and the effects from carbon storage. This paper explores a prospective increase of biobased materials in Swedish buildings, using traditional and dynamic LCA to assess the climate impact effects of this increase. Three alternative designs are analysed; one without biobased material content, a CLT building and an alternative timber design with "increased bio". Different scenario setups explore the sensitivity to key assumptions such as the building's service life, end-of-life scenario, setting of forest sequestration before (growth) or after (regrowth) harvesting and time horizon of the dynamic LCA. Results show that increasing the biobased material content in a building reduces its climate impact when biogenic sequestration and emissions are accounted for using traditional or dynamic LCA in all the scenarios explored. The extent of these reductions is significantly sensitive to the end-of-life scenario assumed, the timing of the forest growth or regrowth and the time horizon of the integrated global warming impact in a dynamic LCA. A time horizon longer than one hundred years is necessary if biogenic flows from forest carbon sequestration and the building's life cycle are accounted for. Further climate impact reductions can be obtained by keeping the biogenic carbon dioxide stored after end-of-life or by extending the building's service life, but the time horizon and impact allocation among different life cycles must be properly addressed.

1. Introduction

Humanity faces an important challenge in climate change which requires immediate mitigation measures according to the latest reports published by the IPCC [1]. As a response to this, several industrial stakeholders, including the building sector, are increasingly looking at the forest as a source of raw materials which can contribute to mitigate their climate impacts by substituting traditional non-biobased materials with biobased alternatives [2].

Life Cycle Assessment (LCA) is a tool which is widely used to compare the environmental performance of different material alternatives. Recently published reviews of LCA in the building sector have concluded that biobased building solutions offer lower environmental impacts in most of the cases if compared to non-biobased building solutions [3,4]. With the increasing

Abbreviations: IPCC, intergovernmental panel for climate change; LCA, Life Cycle Assessment; EPS, expanded polystyrene; CLT, cross-laminated timber; GWP, global warming potential; EoL, end of life; EPD, environmental product declaration.

* Corresponding author at: SP Technical Research Institute of Sweden, Drottning Kristinas väg 67, 114 86 Stockholm, Sweden.

E-mail addresses: Diego.Penaloza@sp.se (D. Peñaloza), Martin.Erlandsson@ivl.se (M. Erlandsson), andreas.falk@byv.kth.se (A. Falk).

http://dx.doi.org/10.1016/j.conbuildmat.2016.08.041
0950-0618/

development of low-energy buildings and energy supply systems with low climate impacts, further reductions can mainly be achieved by optimizing other life cycle stages [5]. This is why for low-energy buildings, processes related to the materials are starting to emerge as the most important contributors to the life cycle impacts of buildings, making the choice of materials more relevant for the life cycle impact of the building [6].

Climate impact assessment of biobased products is a complex subject. The biogenic carbon dioxide sequestration and emissions occur at different times and in different life cycle stages, and some argue that the timing of these exchanges and the alterations to the forest carbon stocks should be taken into account in LCA [7]. Moreover, others dispute that the choice of time horizon for global warming potential (GWP) should be consistent with the studied life time valid in the study [8]. It has also been argued that biobased products with a long service life, such as those used for buildings, store carbon temporarily in the technosphere, reducing the carbon dioxide concentrations in the atmosphere and avoiding radiative forcing [9]. The carbon neutrality of biobased products is often assumed due to the equivalence between the carbon sequestration at the forest level and the biogenic emissions at the end of life, as they are synchronized with the natural carbon cycle [10] [11]. However, carbon neutrality is not the same as climate neutrality and a concept referred as CO_2bio is based on this approach [12]. It is still not common that LCA practitioners account for these dynamic aspects related to climate impact when performing LCA of biobased products [13].

Dynamic LCA is a methodology proposed by Levasseur et al. [8], which makes it possible to account for most of the aspects mentioned above. The method has been used to address the biogenic carbon storage effects in long-lived products such as chairs [15], and more recently in low-energy buildings [14]. This study addresses biogenic carbon using dynamic LCA when comparing timber houses with two non biobased alternatives, including the implications from landfilling at the end-of-life. However, the method has not been used to examine a time horizon that covers both the forest growth, harvesting and then the building life cycle in an order that resembles reality.

The goal of the work presented in this article is to study the climate impact implications of increasing the biobased material contents in low-energy multi-family buildings using Dynamic LCA. An apartment block in Sweden has been used as case study, where three different low-energy design alternatives were analysed with increasing content of biobased materials. The work includes different approaches to account for the biogenic carbon storage in products and for the carbon dioxide sequestration at the forest, as well as alternative service life and end-of-life scenarios. For this, carbon sequestration data for boreal forests is used as part of the inventory data for the manufacturing of the biobased products in the building.

2. Materials and methods

This section presents the method, beginning with a description of the assessed building and the alternative designs analysed with increased biobased materials content, including an outline of the system boundaries of the LCA. Section 2.1 describes the climate impact assessment aspects analysed, and the following subsections after that illustrate the methodology exercised to analyse these aspects.

2.1. About the case study

The case study used in this article is a hypothetical building block located in Stockholm, Sweden. Two designs have been modelled with equivalent functionality in terms of the functional unit (square meters of living area for fifty years); one with a concrete structure and another with cross-laminated timber (CLT) structure, hereby referred to as "CLT design". A third design has been included, referred to onwards as "Increased bio", featuring a higher content of biobased materials than the CLT design. It follows the building system proposed by "Urban Timber", a project recently carried out by students and researchers in collaboration with industrial partners [16]. For the "Increased bio" design, mineral-based insulation and cladding have been replaced with biobased products, and a sprinkler system is included in order to comply with fire protection regulations. In short, the three designs analysed in this study represent increasing levels of biobased material content; the concrete design with zero content of biobased materials, the CLT design with around 50% biobased material content, and the "increased bio" with a prospective maximized biobased material content of 69%.

The main features of the three analysed designs are summarized in Table 1, including exclusions. The excluded materials are similar for all the designs, and therefore they do not contribute to differentiate their biobased materials content. The three designs comply with Swedish passive house standard FEBY12 [17], so equivalent operational energy uses equal to 55 kWh/m^2 have been assumed. Domestic household energy is not accounted for. The two timber-based designs are made of elements prefabricated in northern Sweden, meaning that a high amount of transport is required. The material specifications and amounts for each design used in this study are provided in Appendix A, while an outline of the data references is given in Appendix B.

The system boundaries established for this study are displayed in Fig. 1, which include some of the processes recommended by the EN15804 standard [25]. The studied system includes the forest biogenic carbon sequestration as an input for the manufacturing of biobased products, as well as the emission of this biogenic carbon at the end-of-life. Since this work is focused on aspects of climate impact assessment which are specific to biobased materials, generic assumptions have been used to account for life cycle stages such as transports and construction activities. On the other hand, life cycle stages such as product manufacturing and disposal were modelled with higher level of detailing. The operational energy was modelled using solar power for electricity supply and heat pumps for heat supply. Most of the inventory data used for the LCA calculations was obtained from Ecoinvent; with adjustments to the datasets for material manufacturing and their

Table 1
Main features of the three structures studied.

Key design features	CLT design	Increased bio design	Concrete design
Foundation and ground slab	Concrete and EPS		
Structural elements	Cross-laminated timber (CLT)	Cross-laminated timber (CLT)	Concrete
Insulation in walls and roof	Mineral wool	Cellulose fibre insulation	Mineral wool
Roof elements	Glulam and sawn timber	Glulam and sawn timber	Concrete
Coverings and details	Plywood, sawn timber and gypsum board	Oriented stranded board, plywood and sawn timber	Gypsum board
Extras	None	Sprinkler system (PVC pipes)	None
Manufacturing of elements	In factory	In factory	On-site
Exclusions	Parts that are equal for all designs such as windows, doors, roof asphalt and paint on walls		