

Supplementary electronic materials

Table S1 Field of application of each method

Country	Field of application of each national method applied in this study
AT	<p>Research</p> <p>There is no official ‘Austrian method’, so LCAs within the country might have differences regarding e.g. scope and system boundaries, scenario definitions (transport, replacement, end of life). The declared method is used by the Working Group Sustainable Construction, TU Graz, for the purpose of research projects (e.g. PEF4Buildings). Other methods applied for conducting building LCA in the Austrian context are e.g. methods used within bau:book/eco2soft</p>
AU	<p>GBCA (Green Building Council of Australia) certification and research</p>
BE	<p>Decision-making tool</p> <p>The declared method follows the TOTEM methodology which is mainly used in the design phase by architects (on a voluntary basis). Some public authorities require the use of TOTEM for the design of public buildings.</p>
BR	<p>Research</p> <p>There is currently no national method for whole building LCA in Brazil. The declared method is used by UNICAMP Green Building Lab for academic purposes.</p>
CA	<p>Research and consulting applied to building LCA</p> <p>Consulting is often for LEED certification and EPDs, which does not specify the software. The impact methodology is TRACI 2.1, which is required for LEED certification in North America. The standards are EN 15804 or ISO 14044.</p>
CZ	<p>Decision-making tool and building certification</p> <p>There is no detailed nationally approved approach to carbon accounting. The declared method is used for national building complex quality assessment tool (certification system) SBToolCZ by professionals and authorized personnel.</p>
DE	<p>Building certification (BNB) and research</p> <p>The declared method is used to certify public buildings in Germany. The other widely applied method in Germany is DGNB. The calculation methods behind these two certification systems do not differ much.</p>
DK	<p>Building certification (DGNB Denmark)</p> <p>Currently, the DGNB certification scheme in its adapted version to Danish context is the primary method in Denmark. In mid 2020, the Danish building authorities launch a voluntary sustainability code in the building regulations, with a 2-year test phase. This will become mandatory.</p>

Table S1 Field of application of each method (continued)

Country	Field of application of each national method applied in this study
ES	<p>Research</p> <p>There is no official ‘Spanish method’, so LCAs within the country might have differences regarding e.g. scope and system boundaries, scenario definitions (transport, replacement, end of life). The declared method is used by the University of Seville, for the purpose of research. In Spain, currently also another method based on “ITEC BEDEC” is used, which is a set of databases with information on construction products that provides information on prices, specifications and environmental data, BIM objects library, entity, business, standard budgets and regulation base data.</p>
FR	<p>Decision-making (eco-design) and research</p> <p>The declared method is based on the building LCA tool EQUER (version 5.21.1.2 distributed by IZUBA Energies in Pleiades, 2021, see Peuportier, B., Schalbart, P., Building life cycle assessment tools developed in France, Sixth International Symposium on Life-Cycle Civil Engineering, Ghent, Belgium, October 2018). At the time of assessment E+C- on which is based the new French regulation was still at a testing phase.</p>
NO	<p>Research and Decision-making</p> <p>The declared method is based on the Norwegian standard NS 3720:2018 for GHG emission calculations for buildings. It is based on EN 15978, but also takes into account the life cycle module B8 – transport in use.</p>
NZ	<p>Decision making and certification</p> <p><i>LCAQuick v3.4.2 is a New Zealand tool used to undertake this assessment, which is based on the NZ whole-building whole-of-life framework method. This tool is primarily aimed at informing early design decisions. It has been used on some projects seeking a voluntary environmental rating using the New Zealand Green Building Council’s tool, Green Star.</i></p>
PT	<p>Research and Decision-making</p> <p>In Portugal, it is not mandatory to assess the sustainability of buildings. The SBTool^{PT}-H method declared here is the adaptation of the international Sustainable Building Assessment Tool (SBTool) method to the Portuguese environmental, societal and economic context. The calculation of the potential environmental impacts is based on both generic LCI data and specific data for the Portuguese context (e.g. specific emissions for the Portuguese energy mix is considered). It is primarily used for research.</p>
SE	<p>Certification ((Miljöbyggnad and NollCO2)</p> <p>The assessment was conducted using the free software tool "Byggsektorns Miljöberäkningsverktyg" (“Building sector environmental calculation tool”, hereafter BM) : https://www.ivl.se/sidor/vara-omraden/miljodata/byggsektorns-miljoberakningsverktyg.html. BM is used for assessments such as the Miljöbyggnad 3.0 and NollCO2 certification schemes and only covers module A. It includes a built-in database of GHG emission factors for construction materials. The assessment of B2-4 was added based on default service lives taken from the following report from IVL Swedish Environment Institute: https://www.ivl.se/download/18.343dc99d14e8bb0f58b76ce/1445517742414/B2229.pdf</p>

Table S1 Field of application of each method (continued)

Country	Field of application of each national method applied in this study
SE	<p>Certification ((Miljöbyggnad and NollCO2) The assessment was conducted using the free software tool "Byggsektorns Miljöberäkningsverktyg" ("Building sector environmental calculation tool", hereafter BM) : https://www.ivl.se/sidor/vara-omraden/miljodata/byggsektorns-miljoberakningsverktyg.html. BM is used for assessments such as the Miljöbyggnad 3.0 and NollCO2 certification schemes and only covers module A. It includes a built-in database of GHG emission factors for construction materials. The assessment of B2-4 was added based on default service lives taken from the following report from IVL Swedish Environment Institute: https://www.ivl.se/download/18.343dc99d14e8bb0f58b76ce/1445517742414/B2229.pdf</p>
CH	<p>Building certification (e.g. Minergie-Eco, Swiss standard for sustainable buildings, SNBS) The declared method is mainly based on the national standards SIA 2040:2017 "Energy efficiency path" and SIA 2032:2020 "Grey energy – Environmental life cycle assessment of the construction of buildings".</p>
USA	<p>Certification and research The method declared in based on the Athena Impact Estimator which is a tool developed by the Athena Sustainable Materials Institute (http://www.athenasmi.org/). Currently, there is no agreed upon national method in the US to conduct the life cycle embodied energy assessment of buildings. Athena IE is being used a majority of researchers/practitioners.</p>

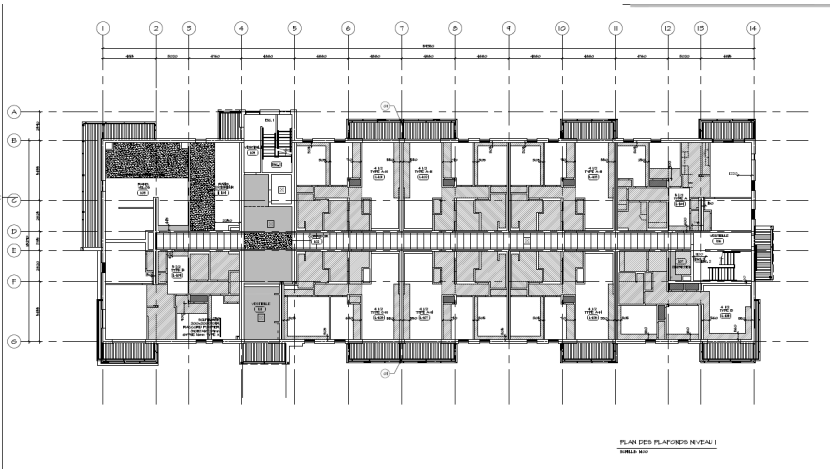
Table S2 Default service life values of the main building components applied in each method

Country	Expected service lives of replaced elements during the RSP [years]					
	Foundation	External walls above ground	Windows	Partition wall and doors (non-supporting)	External coating	External finishes - Roofing
AT	50	50	40	50	30	50
AU	≥60	≥60	25	35	30-50	≥60
BE	60	60	30	30	NA	30
BR	50	40	20	20	40	13
CA	60	60	30	30-60	60	15
CH	60	60	30	30	40	30
CZ	100	50	30	50	30	50
DE	50	50	40	50	NA	30
DK	120	120	40	80	NA	20
ES	50	50	25	25	NA	NA
FR	100	100	30	30	10	30
NO	60	60	60	60	60	60
NZ	100	100	45 - 60	90	60	20-25
PT	50	50	30	30	40	30
SE	50	40	40	50	NA	40
US	50	50	50	50	50	50

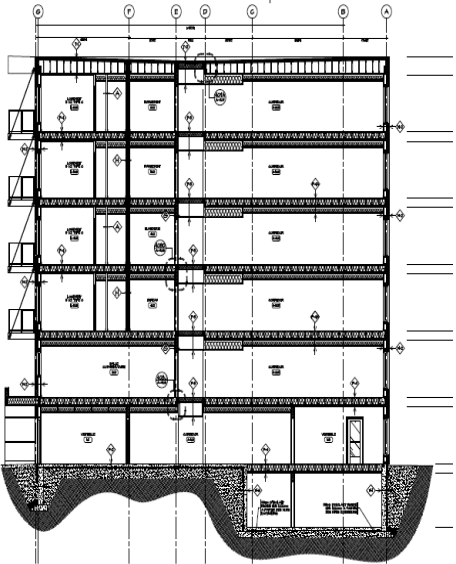
Note: When the elements have as long service lives as the RSP, it means no replacement.



a)



b)



c)

Figure S1: PAL6 multi-residential building a) architectural sketch, b) plan and c) side views.

Description of the three approaches applied in this paper

0/0 approach: It considers neither fixation nor releases of biogenic carbon. **Figure S2**, extracted from Hoxha et al (2020), illustrates the 0/0 approach for a wooden product used in a building. As can be seen in the figure, biogenic CO₂ is not considered in any of the modules. In the cases where wood is landfilled after reaching the end of its service life, the release of biogenic methane (CH₄) is modelled in module C, due to its higher impact on global warming compared to biogenic CO₂. Because biogenic CH₄ emissions shall be and are taken into account, this approach is not to be considered nor called a "climate neutral" approach. Data collection for building LCAs following this approach therefore does not require any consideration of the amount of CO₂ absorbed during forest growth, nor released during the end of life. Since no biogenic CO₂ is accounted for in this approach, only fossil CO₂ emissions take part in the GWP calculation.

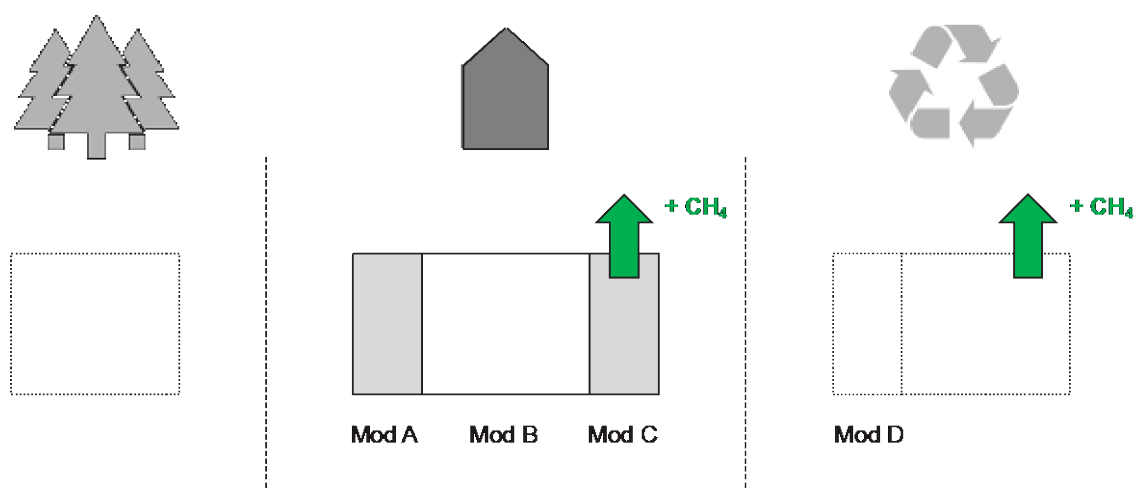


Figure S2: The 0/0 approach to model biogenic carbon uptake and release. The dotted lines indicate the product systems which fall outside the building system boundaries. Source: Hoxha et al (2020b).

-1/+1 approach: it accounts for the fixation of biogenic carbon in the production stage and its release in the end-of-life. Figure S3 (Hoxha et al 2020) illustrates the -1/+1 approach, in which both biogenic CO₂ uptake (-1) and release (+1) are considered, as well as the transfers of biogenic carbon between the different systems. The uptake of biogenic CO₂ during the forest growth is transferred to the building system and reported as a negative emission in module A, whereas at the end-of-life of the building, biogenic CO₂ (or CO or CH₄) is released or the carbon content is further transferred to a subsequent product system (in case of recycling). In both situations a positive emission is reported in module C. It must be noted that the biogenic carbon balance should be zero for all product systems. Also, because biogenic CH₄ emissions shall be and are taken into account, this approach is not to be considered nor called a "climate neutral" approach. Building LCAs conducted with the -1/+1 approach therefore require the calculation of the amount of CO₂ absorbed by the wooden product(s) used in the building, which – at the end of life – will be considered as released in its entirety. It is noteworthy, however, that typical life cycle databases currently do not include detailed, mass-balanced information on the biogenic CO₂ content absorbed by biobased materials during their growth.

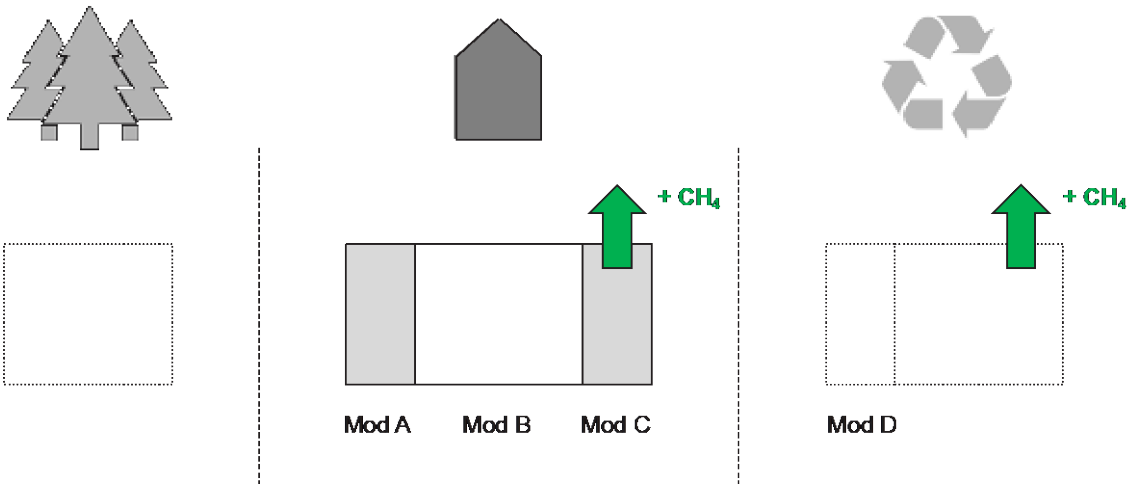


Figure S3: The 0/0 approach to model biogenic carbon uptake and release. The dotted lines indicate the product systems which fall outside the building system boundaries. Source: Hoxha et al (2020).

-1/+1* approach: In some countries, variations of the -1/+1 approach are observed, which are not allowed in others; some countries consider landfills and recycling as a partly permanent storage of biogenic carbon and thus fewer emissions are accounted for in the end-of-life stage (a factor much lower than +1 is used). The -1/+1* means that the fixation of biogenic carbon is considered, but no or not all biogenic carbon is modelled as an emission at the end of life. Preconditions for using such a variant is that landfilling is a national option (for example, in most European countries this is not an option) and a robust scientific basis is in place for degradable organic carbon fraction (DOCf) value for wood in a landfill in a country/jurisdiction.

Carbon footprint assessment of a wood multi-residential building considering biogenic carbon

Claudiane M. Ouellet-Plamondon¹, Livia Ramseier², Maria Balouktsi³, Laetitia Delem⁴, Greg Foliente⁵, Nicolas Francart⁶, Antonio Garcia⁷, Endrit Hoxha⁸, Thomas Lützkendorf³, Freja Nygaard Rasmussen⁹, Bruno Peuportier¹⁰, Jared Butler¹¹, Harpa Birgisdottir⁹, David Dowdell¹¹, Manish Dixit¹², Vanessa Gomes¹³, Maristela Gomes da Silva¹⁴, Juan Carlos Gómez⁷, Marianne Kjendseth Wiik¹⁵, Carmen Llatas⁷, Ricardo Mateus¹⁶, Lizzie M. Pulgrossi¹³, Martin Röck^{8,17}, Marcella Ruschi Mendes Saade⁸, Alexander Passer⁸, Daniel Satola¹⁸, Seongwon Seo⁵, Bernardette Soust Verdaguer^{7,8}, Jakub Veselka¹⁹, Martin Volf¹⁹, Xiaojin Zhang^{20,21}, Rolf Frischknecht²

¹ École de technologie supérieure, Montreal, Canada

² Treeze Ltd, CH- 8610 Uster, Switzerland

³ Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

⁴ Belgian Building Research Institute, 1000 Bruxelles, Belgium

⁵ The University of Melbourne, Parkville VIC 3010, Australia

⁶ KTH - Royal Institute of Technology, 114 28 Stockholm, Sweden

⁷ Universidad de Sevilla, 41004 Sevilla, Spain

⁸ Graz University of Technology, 8010 Graz, Austria

⁹ Aalborg Universitet København, Aalborg Universitet København

¹⁰ MINES ParisTech, PSL Research University, CES, 75272 Paris, France

¹¹ BRANZ, Judgeford 5381, New Zealand

¹² Texas A&M University, College Station, TX 77843, United States

¹³ University of Campinas, 13083-852, Campinas, Brazil

¹⁴ Federal University of Espirito Santo, 29075-910, Vitoria, Brazil

¹⁵ SINTEF, NO-7465 Trondheim, Norway

¹⁶ University of Minho, 4710-057 Braga, Portugal

¹⁷ KU Leuven, 3001 Leuven, Belgium

¹⁸ Norwegian University of Science and Technology, 7491 Trondheim, Norway

¹⁹ University Centre for Energy Efficient Buildings, Czech Technical University in Prague, 273 43, Bustehrad, Czechia

²⁰ Technology Assessment Group, Laboratory for Energy Systems Analysis, Paul Scherrer Institute, Forschungsstrasse 111, 5232 Villigen PSI, Switzerland

²¹ETH Zürich, Institute of Construction and Infrastructure Management (IBI), Chair of Sustainable Construction, Stefano-Francini-Platz 5, 8093 Zürich, Switzerland

Article submitted to the Journal of Cleaner Production, 5 October 2021.