Article citation info:
Pierzchalski M. 2026. Wood and Wood-Based Products in Construction: Carbon Sequestration, Emissions and End-of-Life Scenarios. *Drewno. Prace naukowe. Doniesienia. Komunikaty.* https://doi.org/10.53502/wood-209238

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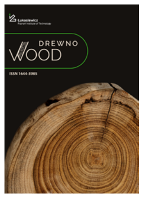
Journal website: https://drewno-wood.pl



Wood and Wood-Based Products in Construction: Carbon Sequestration, Emissions and End-of-Life Scenarios

Michał Pierzchalski [*]

Faculty of Architecture, Environmental Design Department, Warsaw University of Technology

Article info
Received: 10 July 2025
Accepted: 11 August 2025
Published: 20 January 2026

Keywords
life cycle assessment
carbon sequestration
global warming potential
GWP
construction timber
renewable materials
whole life carbon
end-of-life scenarios

This paper examines the climate impacts of using wood and wood-based products in construction, focusing on their carbon sequestration potential, life cycle emissions, and end-of-life scenarios. The analysis is based on Environmental Product Declarations (EPDs) and scientific literature, in accordance with LCA standards such as EN 15804 and ISO 14040. Three forest management strategies—long-rotation forestry, short-rotation plantations, and continuous cover forestry—are compared in terms of their carbon storage efficiency. The study highlights significant differences in greenhouse gas emissions between solid wood and engineered wood products, particularly in the A3 module due to processing intensity. End-of-life scenarios (C1–C4) and benefits beyond the system boundary (D module) have a major influence on the total GWP, with reuse and recycling offering the most favorable outcomes. Incineration with energy recovery partially offsets emissions but eliminates the biogenic carbon storage benefit. Dynamic LCA approaches are recommended for a more accurate assessment of temporal carbon flows. Harmonisation of methodologies across EPDs is essential for credible comparison. The findings support increased use of sustainably sourced wood in construction, provided that product design enables reuse, disassembly, and integration into circular material streams.

DOI: 10.53502/wood-209238

Introduction

The construction sector accounts for more than a third of global greenhouse gas emissions, making the role of low-carbon materials crucial to achieving climate goals. As a renewable natural resource, wood has the ability to store carbon over the long term and has a relatively low carbon footprint associated with its embodied emissions (Caldwell, 2021; Kyllmann, 2024). The use of wood can significantly reduce emissions compared to traditional materials such as steel or concrete (Reyes et al., 2021).

The carbon footprint of wood in construction is assessed using a life cycle assessment (LCA) approach, according to standards such as EN 15804, ISO 14040 and EN 15978 (for buildings). The approach covers the entire life cycle of a building, taking into account not only the production stage (A1–A3), but also the construction stage (A4–A5), the use stage (B1–B7), the end-of-life stage (C1–C4) and the benefits beyond the system boundary (module D).

In recent years, timber technologies in construction have developed dynamically. In addition to traditional solid timber elements, advanced engineered wood products such as cross-laminated timber (CLT) and glulam are increasingly used. This trend is driven by the demand for high-strength materials that support prefabrication and meet sustainability requirements (Early, 2024; Sulik, 2024).

[*] Corresponding author: michal.pierzchalski@pw.edu.pl

Wood is widely perceived as an environmentally friendly material. However, comprehensive assessments of timber technologies are lacking, particularly regarding deforestation risks, the emergence of monoculture plantations, and the accurate accounting of GHG emissions across the full life cycle. Wood is often considered a material with negative emissions, especially when emissions from the end-of-life phase (C1–C4) are omitted. In reality, timber-based construction can only be deemed environmentally beneficial when additional conditions are met, such as sustainable forest management, long-term carbon storage, and well-defined, ecologically responsible end-of-life scenarios.

Life cycle emissions data available in databases and Type III Environmental Product Declarations (EPDs) are often difficult to compare and rarely indicate alternative end-of-life scenarios. Moreover, comparative analyses of EPDs for specific timber products are scarce, making it difficult to evaluate their true environmental impact.

This study addresses part of this gap by highlighting differences arising from the chosen analytical approach and the adopted end-of-life scenarios. Current EPDs do not include dynamic approaches to carbon sequestration for wood or other plant-based materials.

At present, the prevailing method is the static (−1/+1) approach, which assigns a negative emission (−1) at the point of carbon uptake during tree growth and a positive emission (+1) when the carbon is released, such as during combustion or decomposition at the product's end of life. While this method enables the tracking of biogenic carbon flows, it does not account for the timing of those flows, which may distort the actual climate impact.

An alternative is the dynamic approach, based on so-called Dynamic Characterisation Factors (DCF), which consider the timing of emissions and sequestration. One widely used tool is the Bern model, which describes the fraction of CO_2 remaining in the atmosphere over time through a sum of exponential decay functions based on empirical data (Joos et al., 2001). This approach more accurately reflects the delayed sequestration of emissions by the biosphere and oceans, enabling more precise temporal attribution of emissions and better comparisons between timber use strategies (Hoxha et al., 2020; Levasseur et al., 2010).

Dynamic Life Cycle Assessment (Dynamic LCA) approaches, which consider the timing of emissions and removals, offer a more accurate understanding of timber's climate impact than static models. However, there is still no consensus on the calculation methods within this framework. Hoxha et al. (2020), for example, reported substantial differences in results – up to 16% at the building level and between 35% and 200% for individual components – highlighting the significance of methodological choices.

This study examines EPDs of selected timber products available on the European market. The analysis includes a variety of structural materials, ranging from standard solid timber of strength class C24 to different types of glued timber and wood-based products such as oriented strand board (OSB). The impact of plastic-based components on embodied carbon was also considered, enabling a broader assessment of timber technologies in terms of their climate impact.

It is important to note that the publication of Type III EPDs is not mandatory, and their availability for timber construction products is limited. Furthermore, no EPDs were identified that employed a dynamic approach to the assessment of carbon emissions and sequestration.

The primary aim of this study was to compare the climate impacts of various timber products based on Type III EPDs, taking into account end-of-life strategies and forest management practices, and to identify the potential advantages of adopting a dynamic approach within LCA frameworks.

Future research should focus on detailed comparisons of timber products based on their plastic component content, the impact of different end-of-life scenarios, and the application of dynamic LCA methodologies to wood-based materials.

Materials and methods

This study is based on a qualitative and comparative analysis of the life-cycle carbon impact of wood and wood-based building materials. The basic methodological framework is based on the principles of life cycle assessment (LCA), in accordance with ISO 14040:2006 and ISO 14044:2006. In addition, sector-specific rules have been applied, in accordance with EN 15804:2012+A2:2019 and EN 16485:2014, which define product category rules (PCR) for wood and wood-based products.

The assessment considers the full life cycle of timber products used in the construction of buildings, divided into five LCA phases:

1. Production (modules A1–A3);
2. Transportation and assembly (A4–A5);
3. Use phase (B1–B7);
4. End-of-life (C1–C4);
5. Benefits and loads beyond the system boundary (module D).

A comprehensive LCA includes not only the Global Warming Potential (GWP) indicator, but also other impact categories, such as Ozone Depletion Potential (ODP), Acidification Potential (AP), Eutrophication Potential (EP), and Photochemical Ozone Creation Potential (POCP). For timber-based construction products, the highest environmental impacts –particularly with regard to GWP, AP, and POCP – are generated during the production phase.

Due to the growing importance of decarbonising the construction sector and the need for harmonised approaches to environmental impact assessment, this study focuses on the carbon footprint, which is currently the most frequently analysed category in building life cycle assessments. Whole life carbon (WLC) assessments incorporating GWP are already standard in countries such as France, the Netherlands, and Denmark. In line with the revised Energy Performance of Buildings Directive (EPBD 2024), all new buildings in the European Union will be required to calculate their carbon footprint from 2030 onwards.

All life cycle stages of a building are presented in Table 1, with the modules relevant to timber and wood-based products highlighted in bold to indicate their inclusion in this study.

Currently, biogenic carbon emissions and removals are calculated in accordance with EN 15804:2012+A2:2019 and reported separately from fossil-based emissions. In earlier versions of EN 15804, such differentiation was not required.

No software tools were used directly for the research. Instead, data were extracted from Type III Environmental Product Declarations (EPDs) available in public databases such as IBU (Germany) and EPD International (Sweden), as well as from scientific studies (e.g. Cabeza et al., 2022; Cherubini et al., 2011). This approach was applied to both building products and forestry operations, without using specific LCA datasets for forestry activities.

As noted in the introduction, a representative selection of construction-grade timber products was analysed. These included solid structural timber of class C24, finger-jointed glued timber, cross-laminated timber (CLT), hardwood veneer plywood, and oriented strand board (OSB). Selection criteria included: location of production within Europe, compliance with EN 15804+A2, absence of chemical or fire-retardant treatment, availability of data, and representativeness of typical products. The objective was to capture common environmental trends for widely used timber construction technologies. More comprehensive regional representativeness will be addressed in future research stages.

To assess the role of forestry practices in carbon sequestration, the study considered three representative strategies (Chiti et al., 2024; Forest Europe & Liaison Unit Bratislava, 2020; Marston, 2025; Mason et al., 2022):

1. Long-rotation forestry, typical of Central Europe and Scandinavia, involves forest cycles typically lasting between 80 and 120 years. This allows the production of high-density timber suitable for long-rotation applications, and enables forests to act as stable carbon sinks through greater biomass accumulation.
2. Short rotation plantations, typical of industrial forestry (30–40 years), focus on timber volume at the expense of structural quality and often use fast-growing species such as poplar or willow. While efficient in terms of timber supply, they store less carbon in the long term and generate larger amounts of residual biomass.

Table 1. Life cycle stages of a building according to the LCA methodology. Bolded modules indicate those relevant to timber and wood-based products. Author's elaboration based on the EN 15978/15804 standard

Building life cycle																
Product stage			**Construction process stage**		**Use stage**							**End-of-life stage**				**Info**
A1	**A2**	**A3**	**A4**	**A5**	B1	**B2**	B3	**B4**	B5	B6	B7	**C1**	**C2**	**C3**	**C4**	**D**
Raw material supply	**Transport**	**Product manufacturing**	**Transport**	**Construction and installation process**	Use	**Maintenance**	Repair	**Replacement**	Refurbishment	Operational energy use	Operational Water use	**Deconstruction / Demolition**	**Transport**	**Waste processing**	**Disposal**	**Reuse, recovery, recycling potential**

3. Continuous cover forestry (CCF), increasingly promoted in ecological models, relies on selective felling and management of stands of varying ages to maintain continuous forest cover. This maximises carbon storage in biomass and soil, supports biodiversity, and increases forest resilience to climate change and disturbance.

Recent research (Marston, 2025) indicates that CCF provides the most stable long-term carbon sequestration, especially when combined with the production of sustainable wood products. However, its timber yield per hectare may be lower than that of logging systems, which affects the scalability of this strategy. Each forestry regime involves ecological trade-offs and affects land-use dynamics. Short-rotation plantations, although economically attractive and efficient in terms of biomass production, may lead to reduced biodiversity, increased soil erosion, and greater input requirements such as fertilisers or irrigation. In contrast, continuous cover forestry enhances ecosystem resilience and biodiversity but may compete with other land uses due to lower timber yield per hectare. Long-rotation systems effectively maintain carbon stocks but require long-term land commitment, which limits their flexibility in regions facing high development pressure. These differences highlight the need to balance ecological objectives with timber productivity and land availability at the regional scale.

The choice of forest management strategy influences both the quantity and quality of timber harvested and, consequently, the sustainability and environmental impact of the resulting wood products.

It should be noted that the use of Type III Environmental Product Declarations (EPDs) as the primary data source involves certain limitations. Firstly, EPDs are based on assumptions and datasets specific to a particular manufacturer or group of manufacturers, which may hinder the generalisation of results to other regions or technologies. Variations in the energy mix (e.g. the share of renewable energy used in production), typical transport distances, or wood processing methods can substantially affect carbon footprint values and, consequently, limit comparability between different declarations.

Secondly, EPDs vary in scope and level of detail: while some are based on specific data, others rely on generic or average industry data. This can influence the accuracy and consistency of product comparisons. Moreover, although all assessed declarations comply with the requirements of EN 15804:2012+A2:2019 and EN 16485:2014, subtle differences may exist in system boundary definitions, treatment of the use phase, or the inclusion of potential benefits beyond the system boundary (module D).

Therefore, the results presented should be interpreted as an indicative comparative analysis, rather than a precise numerical comparison based on exact unit values.

Results and discussion

1. Modules A1–A3 (product stage)

The cradle-to-gate stage (modules A1–A3) includes the harvesting of raw wood (A1), transport to the processing plant (A2), and production processes (A3). Emissions in this phase depend on a number of factors, such as the distance and means of transport, the source of energy for kiln drying, and the use of auxiliary materials such as adhesives.

In module A1, the EN 15804+A2:2019 standard enables the uptake of biogenic carbon from the atmosphere to be taken into account as a negative contribution to the GWP-biogenic index. For example, according to the Environmental Product Declaration for North American softwood (American Wood Council & Canadian Wood Council, 2020), the stored carbon content is approximately 843.66 kg CO_2e per cubic metre. These figures are consistent with calculations based on the assumption that dry wood mass contains approximately 50% carbon, according to IPCC guidelines (Cabeza et al., 2022). Stored carbon is included as a negative value in module A1 for biogenic emissions.

Transport-related emissions (module A2) depend on the transport distance, vehicle type, fuel type, emission standards, and transport efficiency. According to various sources (Cefik & ECTA, 2011; Department for Energy Security and Net Zero, 2024; European Environment Agency, n.d.; Mulholland et al., 2023), typical emissions for road transport in Europe range from approximately 58 to 140 g CO_2e per tonne-kilometre. For the transport of 1 m^3 of coniferous wood (approximately 500 kg) over a distance of 200 km, these emissions therefore range from approximately 5.8 to 14.0 kg CO_2e.

Module A3 includes cutting, drying and wood preparation operations (e.g. planing). Chamber drying, which ensures the high quality and dimensional stability of structural timber, consumes the most energy. The amount of greenhouse gas emissions associated with chamber drying varies considerably depending on the type of energy source used (Bergman & Bowe, 2008; Loeffler et al., 2016; Puettmann & Wilson, 2005). The energy consumption for drying wood in the case of traditional chamber dryers ranges from 600 to 1000 kWh/m^3, depending on the type and thickness of the wood (Bekkioui, 2021). Most often, the energy for drying comes from fossil fuels such as oal, oil and natural gas (Lamrani et al., 2021;

Loeffler et al., 2016). Lamrani (2021) reports that ventilated dryers emit approximately 345 kg CO_2e per cubic metre of sawn wood.

Additional emissions in module A3 come from electricity consumption during sawing and finishing, and from the use of adhesives, packaging materials and other additives.

Wood can also be air-dried naturally, without energy consumption or greenhouse gas emissions. However, for large sections of wood, this process can take several years – a general rule of thumb is one year of drying for every 2.5 cm of thickness (Meier, n.d.).

From the perspective of reducing the carbon footprint of wood products, the following strategies are recommended:

1. Use of biomass as a heat source, preferably production residues from previous wood processing. The installation of electrostatic filters in chimneys to capture particulates is recommended.
2. Use of waste heat from industrial processes, if the dryer is located near such plants.
3. The use of electricity from renewable sources, such as photovoltaic panels or wind turbines.

The EPD for micro-glued structural timber (Stora Enso, 2020) reports the following cradle-to-gate greenhouse gas emissions (modules A1–A3):

- GWP of fossil origin: 30.6 kg CO_2e/m^3,
- Biogenic GWP: –716 kg CO_2e/m^3,
- Total GWP (net): –685 kg CO_2e/m^3.

These results highlight the important role of biogenic carbon storage in wood products. The negative total GWP value is due to the large amount of carbon stored in wood during tree growth and is recorded in accordance with EN 15804+A2:2019. However, it should be noted that this carbon credit must be balanced by emissions arising during the end-of-life phase (modules C1–C4).

2. Modules A4–A5 (Construction process stage)

As indicated earlier, transport to the construction site (A4) contributes to GHG emissions mainly due to the fuel consumption of transport vehicles. These emissions depend on several factors, including the transport distance, the type of vehicle, its age (emission standards) and the type of fuel. Based on typical European and UK sources (Cefik & ECTA, 2011; Department for Energy Security and Net Zero, 2024; European Environment Agency, n.d.; Mulholland et al., 2023), emissions associated with the transport of timber typically range from 5 to 15 kg CO_2e per m^3 for typical road transport distances.

Emissions associated with assembly (A5) are typically low for timber elements, especially prefabricated elements. They include wear and tear on construction machinery and the management of waste generated on site. Wood waste (offcuts, packaging) is often reused or incinerated with energy recovery, and the associated emissions are included in module A5.

3. Modules B1–B7 (use stage)

Wood products typically do not emit greenhouse gases during use (B1), unless degradation or loss occurs.

Module B2 includes maintenance activities, such as surface impregnation (e.g. oiling) or repainting, which may involve minor emissions from material and energy consumption. The scope and frequency of such activities depend on the product type, its location (e.g. external cladding vs. interior structural elements), and local climatic conditions. For instance, OSB and plywood tend to exhibit lower durability under high-humidity conditions and may require more frequent maintenance than laminated timber or solid KVH timber used in protected structural applications.

Module B3 (repair) is rarely applied to timber or wood-based components, which are generally replaced rather than repaired.

Module B4 accounts for partial or complete replacement of wooden components. Replacement cycles are often based on assumptions related to technical and aesthetic durability. For example, softwood cladding may require replacement every 30–40 years, whereas glulam or CLT structures can remain functional for significantly longer periods, potentially throughout the building's entire service life.

Module B5 includes renovation activities, such as the replacement or upgrading of fixing systems, e.g. for timber façades. In timber construction, the distinction between B4 and B5 is not always clear-cut. Module B5 typically refers to occasional or exceptional interventions (e.g. related to thermal retrofitting), whereas B4 reflects planned replacement at the end of a product's expected service life.

Modules B6 (in-service energy consumption) and B7 (in-service water consumption) do not apply to passive building products, such as beams or timber panels, and are shown as zero in environmental declarations.

Extending the service life of timber products is critical from a carbon accounting perspective, as it enables prolonged storage of biogenic carbon within the material structure and delays its release into the atmosphere. This effect is particularly significant for products with high mass and long potential durability, such as CLT panels, structural beams, or prefabricated wall elements. Research by Brunet-Navarro et al. (2017) indicates that prolonging the lifespan of wood used in buildings contributes linearly to the duration of CO_2 sequestration and constitutes an important strategy for the long-term reduction of greenhouse gas emissions.

4. Modules C1–C4 (end of life phase)

The end-of-life phase includes demolition (C1), transport of recovered materials (C2), waste treatment (C3) and final disposal or recovery (C4). Emissions in this phase are strongly dependent on the end-of-life scenario chosen.

During demolition (C1), emissions come mainly from construction machinery and are usually low. Emissions from transport (C2) depend on the distance and type of load. Waste treatment (C3) can include preparation of materials for recycling (e.g. shredding) or for incineration. Disposal (C4) includes landfilling or incineration without energy recovery.

Different scenarios lead to different end results (Wood Products Council (WoodWorks), n.d.):

1. Combustion with energy recovery: Biogenic CO_2 is immediately released into the atmosphere, but the energy generated can replace fossil fuels, partially offsetting emissions.
2. Storage: This can lead to slow, anaerobic degradation and methane emissions unless gas capture systems are used; however, some biogenic carbon can remain stored for a long time.
3. Recycling: Wood can be recycled into new products, e.g. particleboard, allowing biogenic carbon to be transferred to subsequent material cycles and delaying its emissions.
4. Reuse: Extends the storage period of biogenic carbon in the built environment, further delaying emissions and reinforcing the role of wood as a long-term carbon store.

Examples of end-of-life scenarios for cross-laminated timber (CLT) proposed in the EPD for CLT boards are shown in Table 2.

Increasing the rate of recycling of wood products significantly increases the amount of biogenic carbon retained in the material cycle, extending its storage for multiple life cycles. Recycling allows the same biomass to be reused multiple times, reinforcing the role of wood as a carbon sink and further delaying CO_2 emissions into the atmosphere (Brunet-Navarro et al., 2017).

The reported emissions for modules C1–C4 in EPD declarations vary, but combustion scenarios typically result in high biogenic emissions per m^3 of wood, largely offsetting the negative balance in

Table 2. End-of-life scenarios for Cross-Laminated Timber (CLT) in the EPD for Stora Enso CLT. Author's elaboration based on (Stora Enso, 2023). The values were transcribed from the EPD by converting scientific notation into decimal form (hence the differences in total values)

End-of-life scenario	Emission type	GWP C3 (kg CO_2e / m^3)	GWP C4 (kg CO_2e / m^3)	GWP D (kg CO_2e /m^3)
100% Incineration with energy recovery	fossil	20.2	0	-267
	biogenic	762	0	-0.751
	luluc	0.00227	0	-0.277
	total	782	0	-268
100% Recycling to wood chips	fossil	5.52	0	-15.9
	biogenic	762	0	-0.163
	luluc	0.000551	0	-0.181
	total	768	0	-16.2
100% Reuse in coherent form	fossil	0	0	-44.4
	biogenic	762	0	-0.346
	luluc	0	0	-0.834
	total	762	0	-45.6
100% Landfill with energy recovery	fossil	0	4.3	-0.0454
	biogenic	0	1010	-0.00015
	luluc	0	0.00103	-0.0000557
	total	0	1020	-0.0456

module A1. Recycling and reuse significantly reduce net emissions, as long as the benefits of module D are correctly captured.

Although the environmental benefits of recycling and reuse are well established, their large-scale implementation faces numerous practical, economic, and technical challenges. The dismantling of wood-based building elements for reuse often requires additional labour and careful design features, such as reversible joints, which may not be present in existing

Table 3. Global Warming Potential (GWP) indicators for selected Environmental Product Declarations (EPDs type III) of wood-based products. All values are expressed in kilograms of CO_2 equivalents (kg CO_2 eq.)

Product name	GWP type	A1	A2	A3	C1	C2	C3	C4	D	Country	EPD No.
KVH® structural timber (450 kg/m3)	fossil	14.5	10.8	5.23	-	-	-	-	-	CZ	S-P-02153
	biogenic	-717	0.00636	0.323	-	-	-	-	-		
	land use	0.893	0.00403	0.0754	-	-	-	-	-		
	total	-701	10.9	5.63	-	-	-	-	-		
CLT (470 kg/m3)	fossil	32.6	8.71	11.2	4.01	2.04	20.2	0	-267	AT, CZ, SE	S-P-09949
	biogenic	-762	0.00628	0.34	0.000698	0.000812	762	0	-0.751		
	luluc	0.826	0.00473	0.0476	0.000397	0.000767	0.00227	0	-0.277		
	total	-729	8.72	11.6	4.01	2.05	782	0	-268		
KLH® CLT (470 kg/m3)	fossil		85.3		9.42	3.97	13.6	0	-265	AT	S-P-04195
	biogenic		-762		0	0	762	0	0		
	land use		2.09		0.00094	0.00123	0.00175	0	-0.25		
	total		-675		9.42	3.97	776	0	-265		
KVH® Structural timber (468.62 kg/m3)	total	-728	6.48	40.3	-	0.47	770	-	-425	DE	EPD-SHL-20180036-IBG1-EN
CLT	fossil		93		0	1.41	3.74		-408	AT, DE	EPD-HAS-20210172-IBD1-EN
	biogenic		-754		0	-0.00167	750		-1.42		
	total		-660		0	1.42	753		-410		
Hardwood Veneer Plywood (796,24 kg/m3)	total	-1140	22.3	216	-	2.31	1260	-	-585	DE	EPD-VHI-20210199-IBG1-DE
Płyta OSB (614,5 kg/m3)	total		-890		-	-	1130	-	-616	DE, PL, FR, HU	EPD-KRO-20200203-IBD1-DE
Glued laminated timber (470 kg/m3)	fossil		144		0	1.41	3.74	0	-408	AT, DE	EPD-HAS-20210171-IBD1-EN
	biogenic		-753		0	-0.00167	750	0	-1.42		
	land use		0.781		0	0.0115	0.00529	0	-0.319		
	total		-608		0	1.42	753	0	-410		
C24 Graded, untreated kiln-dried (480 kg/m3)	fossil		47.3		-	0.42	2.58	0	-762	UK	S-P-06869
	biogenic		-746		-	0.000249	0.00327	746	0.0783		
	land use		1.96		-	0.000142	0.000798	0	-0.118		
	total		-697		-	0.42	2.58	746	-762		

structures. In terms of recycling, contamination with adhesives, coatings, or composite materials can reduce the quality and usability of recovered wood. The reuse of reclaimed wood products is further limited by the need to ensure consistent, documented levels of quality and structural performance. Financial incentives for recycling or reuse are often insufficient compared to the low cost of energy recovery or landfill disposal. Overcoming these barriers requires policy support, the standardisation of deconstruction methods, the development of new business models that account for environmental benefits, and the education of designers to apply Design for Disassembly principles.

5. Module D (benefits beyond system boundaries – reuse, recovery, recycling potential)

Module D takes into account environmental benefits occurring beyond the primary product life cycle, often referred to as 'avoided emissions'.

In the case of wood products, these typically relate to:
- substitution of fossil fuels through energy recovery from used wood,
- substitution of primary raw materials through recycling and reuse of materials.

For example, wood waste burned with energy recovery can replace fossil heat and electricity (Stora Enso, 2020). Similarly, the reuse of wood or the recycling of fibres to produce particleboard avoids the need for new wood and synthetic materials.

These 'avoided burdens' are reported as negative GWP values in module D and can significantly affect the final climate balance of wood – especially when the end-of-life strategy is based on recovery rather than disposal. According to EN 15804+A2:2019, these benefits must be transparently reported and separated from the primary life cycle stages.

Table 3 shows the Global Warming Potential (GWP) indicators for selected EPD declarations of wood-based products, split into fossil, biogenic, land-use and total contributions, under stages A1–A3, C1–C4 and D. For stages C3, C4 and D, the values correspond to the default end-of-life scenarios included in the EPD data, without separating out specific options such as reuse, recycling, incineration or landfilling. The results show significant differences, which can be attributed to the variability of production processes, differences in the energy mix (including the share of renewable energy), the scenarios used, and the different approaches taken in the calculations.

High emissions in phase C3 indicate wood combustion; if a negative value appears in module D this means, for example, combustion with heat recovery. High emissions in module A3 indicate energy-intensive processes, e.g. veneer drying, gluing and press operation. For veneers, very high emissions in module C3 (e.g. 1260 kgCO_2e/m^3) are indicative of combustion, in which case we have combustion of the wood and the glue used. High values in module D are indicative of the possibility to reuse OSB, for example, or to use it as raw material for particleboard. Most EPDs emphasise that material recovery and reuse should be preferred to incineration, in line with the principle of cascading resource use.

A comparative analysis of environmental declarations (EPDs) for construction wood products showed significant differences in greenhouse gas (GWP) emissions depending on the material processing, production process and end-of-life scenario adopted. Solid wood products, such as micro-glued timber or C24 graded lumber, have the lowest emissions in the production phase (modules A1–A3), with a significant carbon credit due to biogenic CO_2 storage. In contrast, highly processed materials such as CLT, glulam and plywood show significantly higher production emissions, mainly in module A3, related to the consumption of energy and auxiliary materials (e.g. adhesives). However, the key factor influencing the overall emissions balance is the end-of-life scenario, especially the emissions in module C3 due to wood combustion and the benefits in module D, where energy recovery is taken into account. Products with an end-of-life scenario involving biomass energy recovery and fossil fuel substitution achieve significant reductions in module D emissions (as low as −762 kg CO_2e/m^3), significantly improving their overall environmental profile. The results confirm that a strategy of wood reuse or energy recovery is crucial for balancing emissions across the life cycle of wood products.

Conclusions

The results presented here highlight the dual role of wood as both a carbon sink and a potential source of emissions – depending on how its life cycle is treated. Accurate consideration of biogenic carbon flows is key to obtaining reliable climate impact assessments. The cradle-to-gate phase demonstrates the significant carbon storage capacity of wood, but these benefits need to be carefully balanced against the emissions that occur during the end-of-life phase.

One of the key findings is the significant variation in climate impacts depending on the end-of-life scenario chosen. Incineration leads to a rapid release of stored biogenic carbon, while recycling and reuse can extend the storage period by several decades or longer.

Therefore, the choice of end-of-life strategy is critical to the final Global Warming Potential (GWP) balance of wood products.

Dynamic Life Cycle Assessment (Dynamic LCA) approaches, which take into account the timing of emissions and removals, provide a more precise understanding of the climate impacts of wood than static models. Traditional static approaches, such as the −1/+1 method (instantaneous sequestration and emissions), can distort the true climate value of long-lived wood products.

Varying forest management practices also significantly affect the climatic performance of wood. Continuous cover forestry (CCF), by maintaining continuous forest cover, increases the potential for long-term carbon sequestration compared to short-rotation logging systems. However, CCF typically results in lower commercial timber yields per hectare, which can affect its economic viability.

Finally, harmonisation of emission accounting methodologies in EPDs and regulatory frameworks is urgently needed. Current inconsistencies regarding system boundaries, carbon allocation and assumptions related to substitution effects hinder the comparability of studies and may undermine confidence in the results of LCA analyses. Moving towards dynamic and standardised reporting systems will enhance the credibility of wood as a climate-friendly building material.

Wood and wood-based products can play an important role in decarbonising the construction sector, provided their full life cycle is properly assessed. The results of this study allow the following conclusions to be drawn:

1. Whole Life Carbon Assessment (WLCA) is essential for a reliable assessment of the climate impact of wood. Analyses limited to the cradle-to-gate stage may underestimate future emissions if end-of-life stages (C1–C4) and module D are not properly considered.
2. Storage of biogenic carbon provides significant, albeit temporary, climate benefits, especially when timber is used in permanent structural elements of buildings.
3. Reuse and recycling scenarios extend the carbon storage period and reduce the need for virgin raw materials, providing the most favourable results in life cycle analyses.
4. Incineration with energy recovery provides partial climate benefits by replacing fossil fuels, but completely neutralises the biogenic carbon sequestration credited in module A1, leading to a zero or slightly positive balance.
5. Landfilling of wood waste is generally undesirable due to the potential for methane emissions and loss of value of the material, although some carbon may remain stored for longer periods.
6. Strategies to extend the life and increase the rate of recycling of wood products are key to effective carbon storage and CO_2 reduction. In the short term, recycling of short-lived products such as paper offers rapid benefits, while in the longer term, extending the life of durable products such as structural timber offers greater reduction potential.
7. Forest management practices have a direct impact on the carbon efficiency of wood products. Longer rotation periods and continuous cover forestry promote higher wood quality and more permanent carbon storage.
8. Methodological consistency and transparency in LCA analyses are essential to ensure comparability of results between products and regions. Harmonised implementation of EN 15804+A2 and consistent inclusion of module D as a standard reporting element are recommended.
9. Dynamic approaches in LCA, although still rarely used, are promising tools to more accurately reflect the timing of emissions and should be further developed in future studies.

The findings support the wider use of sustainably sourced wood in buildings and infrastructure, provided that design strategies take into account the possibility of dismantling, reusing and incorporating into circular material streams.

A key contribution of this study is the comparative analysis of EPD data across different end-of-life scenarios and the emphasis on the importance of applying a dynamic LCA approach to the assessment of timber products.

Although this study primarily focuses on environmental indicators, it is important to recognise that socio-economic factors significantly influence material selection, construction practices, and end-of-life product management. For instance, in regions with limited access to skilled labour or higher upfront costs for timber construction, implementation may be constrained despite clear environmental benefits. Future assessments should incorporate these dimensions to better capture the systemic nature of decarbonisation strategies within the built environment.

Moreover, subsequent research should extend the analysis to include additional environmental indicators (e.g. AP, EP, POCP) and further investigate the socio-economic conditions that affect the feasibility and adoption of reuse and recycling strategies.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

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