International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 12 - Issue 10 || October 2026 || PP. 01-12

Life Cycle Carbon Footprints of White Oak Cladding and Louro Gamela Decking Manufactured in Southern Vietnam

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Abstract: This study assessed greenhouse gas emissions from white oak cladding and Louro Gamela decking manufactured in southern Vietnam using factory records and secondary life cycle inventory data. The reference unit was 1 m³ of each finished product. The scope covered production (A1–A3), end-of-life processes (C1–C4), and recovery benefits and burdens (D). Production impacts were approximately 1.05E+03 kg CO_2e/m³ for cladding and 6.60E+02 kg CO_2e/m³ for decking. Manufacturing contributed about 66% of each production result, while fossil contributions represented approximately 98% of A1–A3. End-of-life impacts were approximately 1.80E+02 and 1.16E+02 kg CO_2e/m³, respectively, with disposal as the largest contributor. Module D credits were –3.71E+01 and –2.36E+01 kg CO_2e/m³. Supplementary balances including these credits were approximately 1.19E+03 and 7.53E+02 kg CO_2e/m³. Reported electricity scenario results differed from the production baselines by approximately −2% to −3% and +8%. Comparisons with wood product EPDs and research reporting per cubic metre highlighted differences in service life, recovery scenarios, and biogenic carbon accounting that limit direct performance ranking. The study contributes factory-specific inventories for two finished wood applications in southern Vietnam and identifies manufacturing as the principal hotspot for assessing energy efficiency and material use.

Keywords: Carbon footprint, Life cycle assessment, Louro Gamela decking, White oak cladding, Wood products

1. Introduction

Reducing emissions from construction requires reliable evidence on the materials incorporated into buildings. The United Nations Environment Programme reported that building construction and operation accounted for approximately 34% of global carbon dioxide emissions in 2023 [1]. Wood products can retain carbon taken up during tree growth, but their climate performance also depends on the emissions associated with material supply, processing, transport, and disposal. In Vietnam, the commitment to net zero emissions by 2050 provides a further reason to develop product-level carbon inventories that can inform decisions within the wood processing sector [2].

Life cycle assessment (LCA) provides a framework for tracing environmental burdens across connected production and waste management processes. ISO 14040 and ISO 14044 establish its principles and methodological requirements, while ISO 14067 specifies requirements for quantifying a product carbon footprint [3,4,5]. Applying these frameworks to wood requires transparent treatment of fossil emissions, biogenic carbon flows, and the assumptions governing recovery after use. A recent systematic review of woodworking LCAs identified substantial differences in system boundaries, background data, and assessment methods, emphasizing the need for harmonized modelling and sensitivity analysis [6]. Consequently, carbon storage in a finished timber product should be interpreted within the stated assessment boundary and disposal scenario.

Research on wood flooring offers useful evidence for identifying processes that merit attention in other profiled wood products. Hubbard and Bowe developed a gate-to-gate inventory for solid hardwood flooring in the eastern United States, documenting material consumption, energy demand, coproducts, and emissions [7]. More recently, Lao et al. reported a cradle-to-gate footprint of −8.5 kg CO_2e per square metre for solid wood flooring in China when biogenic carbon storage was included [8]. Their analysis also showed that allocation choices and electricity supply influenced the results. A separate assessment by Lao identified wood inputs and manufacturing electricity as major environmental hotspots across four flooring categories [9]. Together, these studies support examining material yield and energy use in manufacturing, while recognizing that a negative factory-gate balance does not establish a negative footprint over the complete product life cycle.

Environmental product declarations (EPDs) provide additional examples of how assessment assumptions shape reported outcomes. The industry-average declarations for solid and engineered wood flooring report cradle-to-grave global warming potentials of approximately 9.16 and 11.41 kg CO_2e per square metre, respectively, for their landfill scenarios and a 75-year reference service life [10,11]. These figures provide

context for interpreting flooring assessments; they cannot be transferred directly to cladding or decking. Product function, dimensions, maintenance requirements, service life, and end-of-life assumptions must be aligned before environmental performance can be compared. Likewise, results expressed per square metre cannot be compared directly with volume-based inventories without accounting for thickness and the service provided.

Vietnamese research has begun to establish a domestic evidence base for wood product carbon accounting. Nguyen et al. quantified carbon footprints for roundwood, sawnwood, and woodchips from acacia plantations in northeastern Vietnam [12]. A subsequent study by Tang et al. assessed white oak flooring manufactured in Ho Chi Minh City and identified manufacturing as an important source of emissions [13]. These contributions demonstrate the value of locally collected production data, while leaving a need for inventories tailored to other finished products and supply chains. White oak cladding produced from United States lumber and Louro Gamela decking produced from Brazilian lumber involve different material specifications, transport routes, and finishing inputs. Assessing these product systems can therefore extend the evidence available for wood processing in southern Vietnam.

This study assesses greenhouse gas contributions from white oak (*Quercus alba*) cladding and Louro Gamela decking manufactured in southern Vietnam. Primary factory records are combined with secondary inventory data within the methodological framework of ISO 14040, ISO 14044, and ISO 14067. The assessment covers raw material supply, inbound transport, and manufacturing (A1–A3), modelled end-of-life processes (C1–C4), and recovery benefits and burdens beyond the system boundary (D). The objectives are to characterize module contributions, identify emission hotspots, and examine electricity demand scenarios. The products represent distinct applications, and the analysis provides production-specific evidence rather than a comparison of functionally equivalent alternatives.

2. Materials and methods

2.1 Investigated products and manufacturing processes

The study examined two solid wood products manufactured in Ho Chi Minh City, southern Vietnam. White oak (*Quercus alba*) cladding had finished dimensions of 12 × 93 × 1,906 mm and was machined from blanks measuring 16 × 102 × 2,000 mm, with a moisture content of 8–12%. The lumber was imported from the United States through the Port of Baltimore. Louro Gamela decking measured 18 × 105 × 900 mm after processing and was produced from 22 × 120 × 2,100 mm blanks imported through the Port of Paranaguá, Brazil. The imported wood was accompanied by documentation of legal origin and traceability. Both supply chains combined ocean freight with road transport to the factory.

Manufacturing comprised double-sided planing, edge ripping, cross-cutting, coarse sanding, tongue-and-groove profiling, end matching, fine sanding, surface finishing, and packaging. The finishing inputs differed between the products: polyurethane (PU) coating was used for white oak cladding, whereas finishing oil was used for Louro Gamela decking.

2.2 Assessment framework

The assessment was structured with reference to the LCA principles and methodological guidance of ISO 14040:2006 and ISO 14044:2006, together with the product carbon footprint framework of ISO 14067:2018 [3,4,5]. The work was organized into goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation. Each product was treated as a separate system. The study was not designed to substantiate a comparative assertion between functionally equivalent alternatives or to serve as a verified EPD.

2.2.1 Goal and scope definition

The assessment aimed to quantify greenhouse gas contributions from the investigated product systems and locate emission hotspots that could guide mitigation measures. The intended users include researchers and wood manufacturers seeking production-specific evidence on carbon footprints. The geographical scope covered imported material supply chains and processing in southern Vietnam.

The assessment covered production (A1–A3) and end-of-life activities (C1–C4), with recovery benefits and burdens reported separately in module D. A supplementary scenario balance was calculated as A1–A3 + C1–C4 + D. Delivery to site and installation (A4–A5) were excluded because distances, vehicle choices, and installation practices depend on individual projects. Use-stage modules B1–B7 were not modelled. The boundary therefore represents production with end-of-life and recovery scenarios, rather than a complete cradle-to-grave assessment. Table 1 summarizes the scope.

Table 1: Life cycle stages and assessment boundary

Life cycle stage	Module	Activity	Coverage
Product	A1	Raw material supply	Included
Product	A2	Transport to manufacturer	Included
Product	A3	Manufacturing	Included
Construction	A4	Delivery to construction site	Excluded
Construction	A5	Construction and installation	Excluded
Use	B1	Use-related material emissions	Excluded
Use	B2	Maintenance and associated transport	Excluded
Use	B3	Repair and associated transport	Excluded
Use	B4	Replacement and associated transport	Excluded
Use	B5	Refurbishment and associated transport	Excluded
Use	B6	Operational energy consumption	Excluded
Use	B7	Operational water consumption	Excluded
End of life	C1	Deconstruction and demolition	Included
End of life	C2	Transport of waste	Included
End of life	C3	Waste processing	Included
End of life	C4	Final disposal	Included
Beyond system boundary	D	Reuse, recycling, or recovery	Included

2.2.2 Reference unit and system boundaries

The inventory reference unit was 1 m³ of finished white oak cladding and, separately, 1 m³ of finished Louro Gamela decking. This volume-based unit provides a consistent basis for reporting production inputs and outputs, without implying equivalent building functions or service lives. Primary information for A1–A3 was compiled from quantity records held in the manufacturer's data management system for October 2025 to June 2026.

Module A1 covered upstream material supply, A2 covered inbound material transport, and A3 represented factory processing and packaging. The end-of-life model included removal or dismantling (C1), waste transport (C2), processing for recovery (C3), and disposal (C4). Manual dismantling was assumed for C1. Waste transport in C2 was represented by a 50 km journey in a 16-tonne truck. Module D addressed net impacts associated with recovered material entering a subsequent product system.

2.2.3 Inventory compilation and data quality

Inventory data were selected for relevance to the products and processes under study, completeness of material and energy flows, consistency of modelling, accuracy, and transparency [3,4]. Temporal and geographical representativeness were considered alongside the technical correspondence between the data and the manufacturing processes. Primary sources included electricity bills, purchasing documents, material origin records, and manufacturer or supplier measurements. Secondary information was used where direct observations were unavailable.

Data quality was examined in terms of geographical, technological, and temporal representativeness, using five qualitative levels: very good, good, fair, poor, and very poor. Assumption-based information was generally rated fair unless documentary support was available; the assumed waste transport activity was rated poor. Table 2 distinguishes the quality of activity data from that of background datasets. The European Platform on LCA Annex C dataset, version 2.1 of May 2020, was used as a generic reference for recovery assumptions [14]. These assumptions represent scenarios rather than measured Vietnamese end-of-life practices.

Table 2: Inventory sources and qualitative data quality

Module	Required information	Source	Activity data quality	Background quality
A1–A3	Material origin and quantities; electricity consumption	Electricity bills, purchase invoices, and material origin documents	Good	Good
C1	Manual dismantling	Handover records	Good	Good
C2	Vehicle type, distance, and fuel-related activity	Assumed 50 km transport by a 16-tonne truck	Poor	Good
C3	Material recovery fraction	European Platform on LCA (2020) [14]	Fair	Fair
C4	Disposal scenario linked to recovery assumptions	European Platform on LCA (2020) [14]	Fair	Fair
D	Recovered material leaving the product system	European Platform on LCA (2020) [14]	Fair	Fair

2.2.4 Climate change impact assessment

Life cycle impact assessment converted inventory flows into potential climate change contributions. Results are relative indicators of potential impacts; they are not predictions of environmental damage, risk, or threshold exceedance. Climate change was characterized over a 100-year time horizon using IPCC 2021 global warming potentials [15]. Results were expressed in kilograms of carbon dioxide equivalent (kg CO_2e). The reporting structure distinguished total, fossil, biogenic, and land use and land-use change contributions, as summarized in Table 3.

Table 3: Climate change indicators and characterization basis

Indicator	Unit	Characterization basis
Climate change — total	kg CO_2e	IPCC 2021 GWP over 100 years
Climate change — fossil	kg CO_2e	IPCC 2021 GWP over 100 years
Climate change — biogenic	kg CO_2e	IPCC 2021 GWP over 100 years
Climate change — land use and land-use change	kg CO_2e	IPCC 2021 GWP over 100 years

For an individual inventory activity, the associated carbon dioxide equivalent contribution was calculated by multiplying the activity quantity by its corresponding emission or characterized impact factor. Contributions were then summed across the included processes. Consistent documentation of inventory data and factors followed the principles described in international LCA database guidance [16]:

$$GHG\ \ contribution\ \ (kg\ \ CO_2e) = Activity\ \ data\ \ \times Emission\ \ factor \quad (1)$$

Activity data comprised the material, energy, and transport quantities assembled for the inventory. Process factors for materials, energy supply, and transport were obtained from ecoinvent through SimaPro version 9.5.0.1, and the product models were assembled in a spreadsheet. Where a suitable ecoinvent factor was unavailable, information from EPDs was used. The total climate change contribution was expressed as:

$$GWP_{total} = GWP_{fossil} + GWP_{biogenic} + GWP_{LULUC} \quad (2)$$

GWP_{total} denotes the aggregate climate change contribution within the assessed boundary. GWP_{fossil} represents contributions associated with fossil carbon sources, including coal, petroleum, and natural gas. $GWP_{biogenic}$ covers emissions and removals associated with biological carbon. GWP_{LULUC} represents contributions attributable to land use and land-use change, including changes in forest cover or land management. The separation of these components distinguishes the sources of the reported climate change impacts.

2.2.5 Product stage inventory for modules A1–A3

Factory and supplier records were combined with secondary information to describe the product stage. Table 4 presents product-specific A1 inputs, including 1.5345 m^3 of white oak lumber and 1.7334 m^3 of Louro Gamela lumber per cubic metre of finished product. Table 5 gives inbound distances and transport modes.

Table 6 reports the manufacturing inventories, with electricity consumption of 885.83 kWh/m³ for cladding and 623.15 kWh/m³ for decking.

Table 4: Material inputs for module A1 per cubic metre of finished product

Product	Material and specification	Quantity	Unit
White oak cladding	Kiln-dried white oak lumber; moisture 8–12%; density 650 kg/m³	1.5345	m³
White oak cladding	Polyurethane coating	41.67	kg
White oak cladding	502 adhesive	30.97	g
Louro Gamela decking	Kiln-dried Louro Gamela lumber; moisture 8–12%; density 660 kg/m³	1.7334	m³
Louro Gamela decking	Finishing oil	8.33	kg
Louro Gamela decking	502 adhesive	25	g

Table 5: Inbound material transport for module A2

Material	Distance (km)	Transport mode
White oak lumber	20,480	Ocean freight
White oak lumber	41	40-tonne truck
Louro Gamela lumber	18,000	Ocean freight
Louro Gamela lumber	41	40-tonne truck
Polyurethane coating	30	40-tonne truck
Finishing oil	30	40-tonne truck
Polyethylene film	30	40-tonne truck
Strapping	30	40-tonne truck
Wooden pallets	30	40-tonne truck
502 adhesive	5	Motorcycle

Table 6: Manufacturing inventory for module A3 per cubic metre of each finished product

Flow	Resource or output	Quantity	Unit
White oak cladding			
Input	Electricity	885.83	kWh
Input	Diesel	11.67	kg
Input	Corrugated cardboard	45.83	kg
Input	Wooden pallets	34.17	kg
Input	Polyethylene shrink film	8.33	kg
Input	Strapping	8.33	kg
Output	White oak cladding	1	m³
Output	Wood offcuts and dust	347.40	kg
Louro Gamela decking			
Input	Electricity	623.15	kWh
Input	Diesel	8.89	kg
Input	Corrugated cardboard	32.22	kg
Input	Wooden pallets	27.22	kg
Input	Polyethylene shrink film	5.56	kg

Flow	Resource or output	Quantity	Unit
Input	Strapping	5.56	kg
Output	Louro Gamela decking	1	m³
Output	Wood offcuts and dust	484.05	kg

2.2.6 Net benefits and burdens beyond the system boundary

Module D represented the net effects of material recovery after the end-of-waste boundary, using the calculation structure described in the source methodology with reference to EN 15804:2012+A2:2019 [17]. Recovered material leaving the assessed system was balanced against recovered material entering from a previous product system. The resulting net flow was multiplied by the difference between further recovery burdens and the impacts of the substituted primary material, with adjustments for material yield and relative quality:

$$e_D = \sum Y\,(M_{MR,out} - M_{MR,in})\,[E_{MR,after\ EoW,out} - E_{MSub,out} \times \frac{Q_{R,out}}{Q_{Sub}}] \quad (3)$$

In (3), Y is the material yield between the end-of-waste point and the point at which recovered material substitutes another material. $M_{MR,in}$ is the recovered material entering from a previous life cycle, and $M_{MR,out}$ is the recovered mass exported at the end-of-waste boundary. $E_{MR,afterEoW,out}$ describes the impacts per unit of recovered material from subsequent processing. $E_{MSub,out}$ describes the impacts per unit of displaced primary material. $Q_{R,out}/Q_{Sub}$ is the quality ratio between recovered and substituted materials; the source scenario assigns it a value of 1.

The wood recovery scenario assumed a recovery rate of 30% and a quality ratio of 1. Product-specific masses were 561.5 kg for white oak cladding and 620.9 kg for Louro Gamela decking per respective reference unit. The recovered outputs were approximately 168.4 and 186.3 kg, respectively (Table 7). Incoming recovered material was treated as zero in calculating the net exported flows.

Table 7: Product-specific parameters for the wood recovery scenario

Material	Mass (kg)	Recycling rate	Quality ratio	$M_{MR,out}$ (kg)	$M_{MR,in}$ (kg)	Net recovered output (kg)
White oak cladding	561.5	30%	1	168.4	—	168.4
Louro Gamela decking	620.9	30%	1	186.3	—	186.3

2.2.7 Electricity sensitivity scenarios

Electricity demand scenarios represented a 5% reduction and a 15% increase relative to the A3 baselines of 885.83 kWh/m³ for white oak cladding and 623.15 kWh/m³ for Louro Gamela decking. Other inventory inputs and the assessment boundary were held constant. Table 10 presents the electricity quantities and corresponding reported A1–A3 GWP results. The scenarios address electricity demand; changes in electricity supply, material yield, and end-of-life treatment were outside this analysis.

3. Results and discussion

3.1 Product stage impacts for modules A1–A3

The reported production-stage GWP-total was approximately 1.05E+03 kg CO_2e/m³ for white oak cladding and 6.60E+02 kg CO_2e/m³ for Louro Gamela decking (Table 8). For cladding, the A1, A2, and A3 contributions were 1.83E+02, 1.71E+02, and 6.91E+02 kg CO_2e/m³, respectively. The corresponding values for decking were 1.15E+02, 1.11E+02, and 4.34E+02 kg CO_2e/m³. Manufacturing accounted for about 66% of the production-stage result for both products. Upstream material supply and inbound transport each contributed approximately 16–17%. The pattern identifies factory processing as the largest included production hotspot, while showing that imported material supply chains remain relevant.

Fossil contributions were 1.03E+03 kg CO_2e/m³ for cladding and 6.49E+02 kg CO_2e/m³ for decking, approximately 98% of their respective reported A1–A3 totals. Biogenic contributions were positive at 6.05E+00 and 3.87E+00 kg CO_2e/m³, while land use and land-use change contributed 1.01E+01 and 6.61E+00 kg CO_2e/m³. Fossil contributions therefore dominated the reported production results. These impact indicators do not constitute a separate measurement of carbon stored in the finished boards.

The factory inventories show electricity demands of 885.83 and 623.15 kWh/m³ for cladding and decking, respectively. The products also differ in finishing inputs, with PU coating used for cladding and

finishing oil for decking. The aggregate A3 results identify manufacturing as the principal production hotspot while the contributions of individual machines, finishing materials, diesel, and packaging remain aggregated.

The prominence of manufacturing is consistent with the process-level evidence reported by Puettmann et al. [18], who identified manufacturing as the most energy-intensive stage in cradle-to-gate inventories of lumber and solid-strip hardwood flooring. Energy demand and GWP are different indicators, so this agreement concerns the location of production hotspots rather than their numerical magnitude. In the present study, identifying A3 as the largest production contributor provides a practical basis for prioritizing factory energy and material-use assessments. It does not, by itself, quantify the savings achievable from a particular intervention.

Table 8: Production-stage climate change results in kg CO_2e per m^3 of finished product

Product	Indicator	A1	A2	A3	A1–A3
White oak cladding	Biogenic	3.84E–01	3.42E–02	5.63E+00	6.05E+00
White oak cladding	Fossil	1.73E+02	1.71E+02	6.85E+02	1.03E+03
White oak cladding	Land use and land-use change	9.51E+00	1.44E–01	4.77E–01	1.01E+01
White oak cladding	Total	1.83E+02	1.71E+02	6.91E+02	1.05E+03
Louro Gamela decking	Biogenic	2.46E–01	2.19E–02	3.61E+00	3.87E+00
Louro Gamela decking	Fossil	1.09E+02	1.11E+02	4.30E+02	6.49E+02
Louro Gamela decking	Land use and land-use change	6.22E+00	9.15E–02	3.06E–01	6.61E+00
Louro Gamela decking	Total	1.15E+02	1.11E+02	4.34E+02	6.60E+02

GWP values are displayed in scientific notation to three significant figures. Aggregated results are rounded independently, so displayed components may not sum exactly to the displayed totals. No separate carbon-storage credit is added.

3.2 Delivery and installation for modules A4–A5

Delivery and installation were outside the assessment boundary. The results consequently exclude transport to the construction site, fixing materials, installation energy, and on-site losses associated with an installed cladding or decking system.

3.3 Use-stage coverage for modules B1–B7

Cleaning, recoating, repair, and replacement during use were not quantified. Although the products use PU coating and finishing oil, respectively, no maintenance schedule or reference service life was established. The results therefore exclude the impacts associated with coating renewal and replacement during service.

The relevance of maintenance is illustrated by the Accoya–Teknos cladding EPD [19], which reports a B2 contribution of 6.27E+01 kg CO_2e/m^3 from repainting over a 60-year service life. This contribution is specific to that EPD and is not included in the present product inventories.

Heidari et al. [20] likewise identified manufacturing and use as major contributors in a cradle-to-grave assessment of solid hardwood flooring. This finding supports the relevance of manufacturing-focused inventories while demonstrating that the dominant stages can change when service-life activities are included. The present results contribute evidence on production in southern Vietnam within this narrower boundary.

3.4 End-of-life impacts and recovery beyond the system boundary

3.4.1 Manual dismantling in module C1

C1 was assigned zero for both products under the scenario of manual dismantling without powered equipment.

3.4.2 Waste transport and treatment in modules C2–C4

Under the 50 km waste transport scenario, C2 contributed 7.67E+00 kg CO_2e/m^3 for cladding and 7.74E+00 kg CO_2e/m^3 for decking. Processing in C3 contributed 2.26E+01 and 1.44E+01 kg CO_2e/m^3, respectively. C4 was the largest end-of-life module, at 1.50E+02 kg CO_2e/m^3 for cladding and 9.42E+01 kg CO_2e/m^3 for decking. Together, C1–C4 contributed approximately 1.80E+02 and

1.16E+02 kg CO_2e/m^3 (Table 9). Disposal accounted for approximately 83.2% and 81.0% of these end-of-life totals, respectively.

The C4 biogenic contributions were 1.53E+02 and 9.56E+01 kg CO_2e/m^3, whereas the fossil contributions were –2.26E+00 and –1.45E+00 kg CO_2e/m^3. Disposal impacts were thus dominated by the modelled biogenic component. The results are aggregated by indicator and do not distinguish individual gas flows or landfill gas management processes. Recovery rates and disposal conditions represent scenario assumptions rather than observed end-of-life practices in Vietnam.

3.4.3 Recovery benefits in module D

The reported module D credits were –3.71E+01 kg CO_2e/m^3 for cladding and –2.36E+01 kg CO_2e/m^3 for decking. Fossil credits of –3.68E+01 and –2.34E+01 kg CO_2e/m^3 dominated these values. Table 7 specifies recovered wood outputs of 168.4 and 186.3 kg per product reference unit at a 30% recovery rate and a quality ratio of 1. Module D is reported as an aggregate result, without a breakdown between wood and packaging.

The reported recovery credits were equivalent to approximately 3.0% of the combined production and end-of-life burden for each product. The supplementary balance including D remained positive for both products.

The distinction between production burdens and recovery scenarios also has practical value. Bergman et al. [21] assessed new and recovered wood products alongside alternative end-of-life routes, including reuse, energy recovery, and landfill configurations. Their approach illustrates why recovery outcomes depend on the selected route and the displaced product or energy source. Reporting module D separately in the present study makes this scenario dependence explicit and avoids treating future recovery benefits as reductions already achieved in manufacturing.

Table 9: End-of-life impacts and recovery credits in kg CO_2e per m^3

Product	Indicator	C1	C2	C3	C4	D
White oak cladding	Biogenic	0.00E+00	2.82E–03	1.41E–02	1.53E+02	–1.63E–01
White oak cladding	Fossil	0.00E+00	7.66E+00	2.25E+01	–2.26E+00	–3.68E+01
White oak cladding	Land use and land-use change	0.00E+00	6.00E–03	6.68E–02	5.99E–05	–1.27E–01
White oak cladding	Total	0.00E+00	7.67E+00	2.26E+01	1.50E+02	–3.71E+01
Louro Gamela decking	Biogenic	0.00E+00	1.81E–03	8.47E–03	9.56E+01	–1.03E–01
Louro Gamela decking	Fossil	0.00E+00	7.73E+00	1.44E+01	–1.45E+00	–2.34E+01
Louro Gamela decking	Land use and land-use change	0.00E+00	3.54E–03	3.96E–02	3.68E–05	–7.68E–02
Louro Gamela decking	Total	0.00E+00	7.74E+00	1.44E+01	9.42E+01	–2.36E+01

3.5 Emission contributions and supplementary scenario balance

Production and end-of-life processes together contributed approximately 1.23E+03 kg CO_2e/m^3 for white oak cladding and 7.76E+02 kg CO_2e/m^3 for Louro Gamela decking. Production represented about 85.3% and 85.0% of these totals, respectively. Using the same totals as denominators, A3 contributed approximately 56.2% and 55.9%, while C4 contributed about 12.2% and 12.1%. The approximately 66% manufacturing share therefore describes A1–A3 alone.Fig. 1 illustrates the reported GWP contributions by module for the two products. Production (A1–A3) accounts for the largest contribution, followed by disposal (C4), while module D provides a smaller negative contribution associated with recovery.

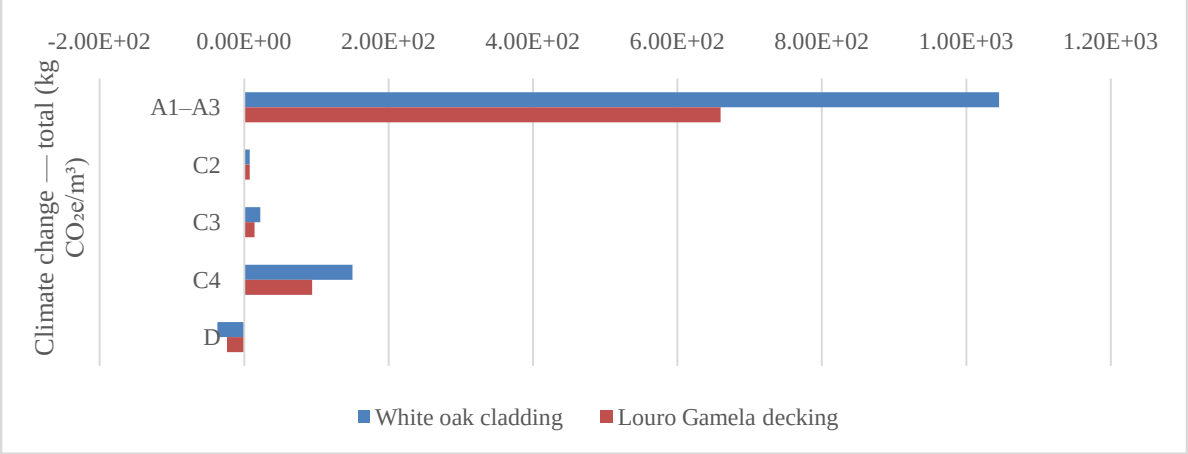

Fig. 1. GWP contributions from production (A1–A3), end-of-life modules (C2–C4), and recovery beyond the system boundary (D) for white oak cladding and Louro Gamela decking. Note: Values are expressed in kg CO_2e/m^3. Negative values in module D represent recovery credits beyond the system boundary. Module C1 is omitted because its modelled contribution is zero.

The supplementary balance A1–A3 + C1–C4 + D was approximately 1.19E+03 kg CO_2e/m^3 for cladding and 7.53E+02 kg CO_2e/m^3 for decking. This balance includes recovery credits beyond the system boundary and excludes delivery, installation, and use. Manufacturing remained the largest included module for both products, identifying factory processing as a priority for evaluating emission-reduction measures.

3.6 Sensitivity to manufacturing electricity demand

Table 10 reports electricity demand scenarios of −5% and +15% for each product. The corresponding reported A1–A3 GWP values were 1.02E+03 and 1.13E+03 kg CO_2e/m^3 for cladding, and 6.44E+02 and 7.13E+02 kg CO_2e/m^3 for decking. Relative to the A1–A3 values in Table 8, these represent differences of approximately −2.9% and +7.6% for cladding and −2.4% and +8.0% for decking.

These endpoints describe the reported scenarios and are not a probabilistic uncertainty interval. The analysis does not quantify changes in the electricity supply mix or establish a marginal emission factor from the rounded GWP endpoints.

Table 10: Electricity sensitivity scenarios on the A1–A3 reporting basis

Product	Baseline electricity (kWh/m³)	−5% electricity (kWh/m³)	+15% electricity (kWh/m³)	Low GWP (kg CO_2e/m^3)	High GWP (kg CO_2e/m^3)
White oak cladding	885.83	841.54	1018.71	1.02E+03	1.13E+03
Louro Gamela decking	623.15	591.99	716.62	6.44E+02	7.13E+02

3.7 Comparison with LCA studies and EPDs reporting per cubic metre

The comparison uses sources with a declared unit of 1 m³: Russwood Accoya–Teknos cladding S-P-07185 [19], Scotlarch cladding [22], Kebony Clear decking with selected indicators revised in March 2025 [23], and ThermoWood Red Oak published in 2025 [24]. Table 11 presents the results for the same module subset. Differences in function, processing, service life, characterization factors, and biogenic carbon accounting still prevent these data from establishing a ranking of functionally equivalent products.

Table 11: Climate change results per declared cubic metre in kg CO_2e/m^3

Product and source	A1–A3 total	A1–A3 fossil	C1–C4 total	D	Supplementary balance including D
White oak cladding, this study	1.05E+03	1.03E+03	1.80E+02	–3.71E+01	1.19E+03
Louro Gamela decking, this study	6.60E+02	6.49E+02	1.16E+02	–2.36E+01	7.53E+02

Product and source	A1–A3 total	A1–A3 fossil	C1–C4 total	D	Supplementary balance including D
Accoya–Teknos cladding, S-P-07185 [19]	3.74E+02	1.15E+03	8.06E+02	–8.19E+02	3.61E+02
Scotlarch cladding, S-P-07186 [22]	–7.72E+02	5.90E+01	8.66E+02	–9.25E+02	–8.31E+02
Kebony Clear decking, NEPD-3659-2604 [23]	–1.08E+03	4.01E+02	1.07E+03	–6.82E+02	–6.93E+02
ThermoWood Red Oak, MRPI 1.1.00820.2025 [24]	–7.19E+02	3.89E+02	1.14E+03	–2.95E+01	3.88E+02

Supplementary balance = A1–A3 + C1–C4 + D. Module D represents benefits and burdens beyond the system boundary. The balance excludes delivery, installation, and use-stage terms. Study balances use the reported totals in Tables 8 and 9; EPD balances use the published module values. Accoya and Scotlarch use a 60-year reference service life; Kebony models replacement after 30 years within a 60-year building assessment. Service-life equivalence with the present products is not established.

The Accoya profiled cladding coated with Teknos EPD S-P-07185 declares 1 m³ [19]. A1–A3 GWP-total is 3.74E+02 kg CO_2e/m³, with fossil and biogenic contributions of 1.15E+03 and –7.74E+02 kg CO_2e/m³. C4 contributes 8.02E+02 kg CO_2e/m³, and module D is –8.19E+02 kg CO_2e/m³. The supplementary balance for the selected modules is approximately 3.61E+02 kg CO_2e/m³. Including the additional declared modules A4, A5, and repainting in B2 gives approximately 4.73E+02 kg CO_2e/m³. Biogenic uptake and subsequent release contribute to the difference between total and fossil indicators.

Scotlarch provides an untreated cladding reference, with A1–A3 GWP-total of –7.72E+02 kg CO_2e/m³ and a fossil component of 5.90E+01 kg CO_2e/m³ [22]. Stored biogenic carbon is released in the end-of-life model, and energy substitution generates a recovery credit of –9.25E+02 kg CO_2e/m³. The resulting supplementary balance of approximately –8.31E+02 kg CO_2e/m³ is strongly influenced by this credit. Such a negative scenario result does not demonstrate permanent atmospheric carbon removal.

Kebony Clear decking has A1–A3 GWP-total of –1.08E+03 kg CO_2e/m³, a fossil component of 4.01E+02 kg CO_2e/m³, and a recovery credit of –6.82E+02 kg CO_2e/m³ [23]. The supplementary balance for the selected modules is approximately –6.93E+02 kg CO_2e/m³. The complete declaration also covers installation, delivery, and replacement. Its large negative biogenic contribution and energy recovery scenario distinguish it from the Louro Gamela model.

The ThermoWood Red Oak declaration, published in April 2025, reports 1 m³ of product [24]. A1–A3 GWP-total is –7.19E+02 kg CO_2e/m³, with a fossil contribution of 3.89E+02 kg CO_2e/m³. C1–C4 contribute approximately 1.14E+03 kg CO_2e/m³, while the recovery credit is –2.95E+01 kg CO_2e/m³, giving a supplementary balance of approximately 3.88E+02 kg CO_2e/m³. The model assumes 95% incineration and 5% landfill and uses Belgian electricity with a photovoltaic contribution. This hardwood reference differs from the present study in species, thermal modification, energy supply, and disposal conditions.

A peer-reviewed cubic-metre study provides a further manufacturing context. Bergman et al. assessed 1 m³ of planed redwood decking using data from four northern Californian mills [25]. They reported gate-to-gate energy use of 1.36 GJ/m³ and fossil and biomass CO_2 emissions of 52.9 and 20.9 kg CO_2/m³. These gas-specific CO_2 inventory results describe a different indicator from GWP-total and are discussed separately from Table 11. The study nevertheless shows the relevance of processing energy, coproduct allocation, and the reporting boundary when interpreting decking inventories.

The supplementary balances for the investigated cladding and decking were approximately 1.19E+03 and 7.53E+02 kg CO_2e/m³, respectively. Their positive A1–A3 biogenic contributions differ from the negative uptake reported in the comparison EPDs. Together with differences in service life and recovery scenarios, this accounting difference limits interpretation of the numerical contrasts. Table 11 provides methodological context rather than a ranking of environmental performance.

The contribution of this study is the combination of factory-specific activity data and module-level climate indicators for two distinct finished wood products manufactured in southern Vietnam. The inventories link imported lumber supply chains with local processing and product-specific finishing inputs. This provides a documented reference for subsequent assessments of the same production systems and extends the Vietnamese evidence discussed in Section 1 beyond the product applications covered by the cited domestic studies. Its practical value lies in identifying where production impacts are concentrated and making end-of-life assumptions explicit, rather than establishing a universal environmental ranking.

3.8 Study limitations

The assessment is limited to the selected modules, production inventories, and end-of-life scenarios. It excludes installation, maintenance, and replacement, and does not establish equivalent service lives for the products. Electricity scenarios address a single input, and no probabilistic uncertainty assessment or statistical comparison was performed. The reported results are aggregated by module rather than by individual manufacturing activity or recovery process.

The inventory and recovery parameters do not establish a closed material and biogenic carbon balance. The results therefore support interpretation of the reported module contributions within the stated boundary, but not claims of permanent carbon removal or full life-cycle superiority over other products.

4. Conclusion

The assessment identified manufacturing as the main emission hotspot for white oak cladding and Louro Gamela decking manufactured in southern Vietnam. A1–A3 GWP-total was approximately 1.05E+03 and 6.60E+02 kg CO_2e/m^3, respectively, with A3 contributing about 66% of each production result. Fossil contributions accounted for approximately 98% of the production totals. Electricity consumption was 885.83 kWh/m^3 for cladding and 623.15 kWh/m^3 for decking. These findings support closer assessment of manufacturing energy and material efficiency.

End-of-life processes contributed approximately 1.80E+02 kg CO_2e/m^3 for cladding and 1.16E+02 kg CO_2e/m^3 for decking, with disposal accounting for about 83% and 81%, respectively. Production and end-of-life burdens were approximately 1.23E+03 and 7.76E+02 kg CO_2e/m^3. Module D credits were reported separately at –3.71E+01 and –2.36E+01 kg CO_2e/m^3. The supplementary balances including these credits were 1.19E+03 and 7.53E+02 kg CO_2e/m^3. The reported electricity scenario endpoints differed from the production baselines by approximately −2% to −3% and +8%.

The study contributes factory-specific inventories for white oak cladding and Louro Gamela decking manufactured in southern Vietnam and identifies manufacturing as the principal reported emission hotspot. These results provide a basis for prioritizing assessments of factory energy use and material efficiency. Separate reporting of module D clarifies the contribution of recovery assumptions to the supplementary balance. Comparisons with published wood-product assessments place the findings in context, while differences in function, biogenic carbon accounting, and service life preclude a direct performance ranking.

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