6

Environmental Product Declaration
Glued Laminated Timber (Glulam)

Environmental Product Declaration (EPD)
in accordance with ISO 14025 and EN 15804

EPD Registration No. S-P-00565 | Version 1
Issued 8 December 2017 | Valid until 8 December 2022

Geographical Scope: Australia

AUSTRALASIA EPD®
ENVIRONMENTAL PRODUCT DECLARATION

WoodSolutions
design and build
woodsolutions.com.au

Environmental Product Declarations

WoodSolutions has developed a suite of EPDs for industry-average, Australian-produced timber products.

These EPDs help to showcase the environmental credentials of Australian wood products. They also provide life cycle data for calculating the impacts of wood products at a building level.

EPDs include:

#01 Softwood Timber

#02 Hardwood Timber

#03 Particleboard

#04 Medium Density Fibreboard (MDF)

#05 Plywood

#06 Glued Laminated Timber (Glulam)

Cover image:
Dorrigo Health and Wellbeing Centre
by Regional Architects Pty Ltd

Photo credit:
Sinclair Black – Coastal Media

WoodSolutions is an industry initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction.

WoodSolutions is resourced by Forest and Wood Products Australia (FWPA). It is a collaborative effort between FWPA members and levy payers, supported by industry peak bodies and technical associations.

This work is supported by funding provided to FWPA by the Commonwealth Government.

ISBN: 978-1-925213-48-5

Researchers:
thinkstep Pty Ltd,
25 Jubilee Street, South Perth WA 6151, Australia

Stephen Mitchell Associates,
PO Box 309, Earlwood NSW 2206, Australia

Produced: December 2017

EPD Details

An Environmental Product Declaration, or EPD, is a standardised and verified way of quantifying the environmental impacts of a product that is based on a consistent set of rules known as a PCR (Product Category Rules).

EPDs within the same product category from different programs may not be comparable. EPDs of construction products may not be comparable if they do not comply with EN 15804.

Declaration owner:

Forest and Wood Products Australia Ltd
Web: www.fwpa.com.au
Email: info@fwpa.com.au
Post: Level 11, 10-16 Queen Street, Melbourne VIC 3000, Australia

EPD produced by:

thinkstep Pty Ltd
Web: www.thinkstep.com
Email: anz@thinkstep.com
Post: 25 Jubilee Street, South Perth WA 6151, Australia

Stephen Mitchell Associates
Email: steve@smassociates.com.au
Post: PO Box 309, Earlwood NSW 2206, Australia

EPD program operator:

The Australasian EPD® Programme Ltd
Web: www.epd-australasia.com
Email: info@epd-australasia.com
Post: c/o Kendons Chartered Accountants
PO Box 31045, Lower Hutt 5040, New Zealand

CEN standard EN 15804 served as the core PCR

PCR:
PCR 2012:01 Construction products and Construction services, Version 2.2, 2017-05-30

PCR review was conducted by:
The Technical Committee of the International EPD® System.
Chair: Massimo Marino. Contact via info@environdec.com.

Independent verification of the declaration and data, according to ISO 14025:
☐ EPD process certification (Internal)
☑ EPD verification (External)

Third party verifier

Kimberly Robertson, Catalyst Ltd
Web: www.catalystnz.co.nz
Email: kimberly.robertson@catalystnz.co.nz
Post: PO Box 37228, Christchurch 8245, New Zealand

Accredited or approved by: The Australasian EPD® Programme

Introduction

This Environmental Product Declaration presents the average performance of glued-laminated timber (glulam) manufactured in Australia from Australian grown wood. It recognises the importance of transparency by providing information on the raw materials, production and environmental impacts of Australian glulam.

This EPD has been prepared in accordance with ISO 14025:2006, EN 15804:2013 and PCR 2012:01 (IEPDS 2017). In addition to decorative glulam it covers structural glulam timbers produced in accordance with the following standard:

- *AS/NZS 1328.1:1998 Glued laminated structural timber - Performance requirements and minimum production requirements*

The environmental data presented in this document are primarily derived from a survey of industry members covering the 2015/16 financial year conducted by thinkstep and Stephen Mitchell Associates on behalf of FWPA. This study covers approximately 64% of total glulam production in Australia.

Production of this EPD has been facilitated by FWPA with the participation of its current glulam-producing members and producer members of the Glued Laminated Timber Association of Australia (GLTAA).

The following companies contributed to this EPD:

Company	Financial contributor	Data contributor
Australasian Sustainable Hardwoods	X	X
Hyne	X	X
VicBeam		X
Warrnambool Timber Industries		X

Description of the Australian Glulam Industry

The Australian glulam manufacturing industry grew out of the need to make better use of short fall down sawn timber and to add value to that resource. Annual glulam consumption in Australia is approximately 30,000 cubic metres, which is 0.6% of total timber consumption (GLTAA 2017). In 2015-16, Australian structural glulam was primarily produced in six different facilities. These producers also produce decorative glulam. There are numerous other producers of decorative glulam products in Australia.

Description of Glulam Products

Glulam is a type of engineered wood product made up of a number of layers of sawn timber bonded together with adhesives. This process produces larger size and longer length members, which can be curved or straight. Timbers used in the production of glulam are typically finger-jointed into continuous lengths and available in a range of both softwood and hardwood species. The thickness of the laminates depends on the application and species used.

Glulam products are either structural or decorative (non-structural) for use in domestic, commercial, and industrial buildings in indoor or outdoor applications. The manufacturing process for both decorative and structural glulam is the same. The major difference is that structural products are graded against standardised structural properties, such as strength, stiffness and dimensional stability.

Common structural glulam applications include:

- Lintels
- Bearers
- Roof beams
- Rafters
- Curves
- Columns
- Portal frames
- Garage beams.

Structural glulam is also increasingly finding applications in midrise residential apartments and commercial construction projects. It can be used in combination with other timber products, such as cross-laminated timber (CLT), as was done in C2 International House Barangaroo, Australia's first engineered timber office building.

Common decorative glulam products include:

- Kitchen benchtops and countertops
- Commercial and domestic joinery
- External screening
- Stair treads and stringers
- Cabinet doors
- Furniture, such as seating and tables.

Glulam can be made from naturally durable timber species and preservative treated softwood species for additional external uses.

Use of EPDs in Building and Infrastructure Rating Systems

This EPD complies with the requirements for an industry-wide EPD under the Green Building Council of Australia's Green Star rating system given that:

1. It conforms with ISO 14025 and EN 15804.
2. It has been verified by an independent third party.
3. It has at least a cradle-to-gate scope.
4. The participants in the EPD are listed.

It may be used by project teams using the *Design & As Built* and *Interiors* rating tools to obtain Green Star points under the following credits:

- Materials > Product Transparency and Sustainability.
- Materials > Life Cycle Assessment: By providing data for an EN 15978 compliant whole-of-building whole-of-life assessment.
- Innovation Challenge > Responsible Carbon Impact: By providing embodied carbon impacts (i.e. data on Global Warming Potential) which can be used in the calculation and reduction of the total embodied carbon impacts of a project.

The use of structural glulam as a part of a substantially timber structure may also make a project eligible for points under the Materials/Life Cycle Impacts – Structural Timber pathway in the *Design & As Built* tool.

This EPD is also recognised for credits in the Infrastructure Sustainability (IS) rating scheme of the Infrastructure Sustainability Council of Australia (ISCA).

Scope

Products

This Sector EPD describes the following average products (declared units) manufactured in Australia by the companies listed in the Introduction:

- 1 m^3 of untreated softwood glulam
- 1 m^3 of hardwood or cypress pine glulam

The results in the main body of this EPD are for untreated glulam. Information on preservative treatment can be found in the Additional Environmental Information section. The results for the specific treatment type used can be added to the results for untreated glulam to calculate the environment profile for treated glulam.

The declared units above represent an entire product category rather than a specific product from a specific manufacturer. The values represent a production volume weighted average. As such, a specific product purchased on the market may have a lesser or greater environmental impact than the average presented in this EPD. Some products may also undergo further processing (e.g. fabrication into an engineered roof truss) before being used in a building.

Wood used in these products is Australian-grown exotic (non-native) softwood species grown in plantations as well as native hardwood and cypress species grown in native forests.

The dominant softwood species used to produce softwood glulam in Australia is *Pinus elliottii* (slash pine) followed by *Pinus radiata* (radiata pine). Another softwood species that may be used is *Pinus caribaea* (Caribbean pine) and its hybrids.

The native hardwood species are a variety of species harvested in NSW, Queensland, Victoria and Tasmania. The most common species used for structural glulam are those known as Victorian ash (*Eucalyptus delegatensis* and *Eucalyptus regnans*). Spotted gum (*Corymbia maculata, Corymbia citriodora* and *Corymbia henrii*), Tasmanian oak (*Eucalyptus delegatensis, Eucalyptus regnans*, and *Eucalyptus obliqua*) and other south-east Queensland hardwood species may also be used.

Cypress pine (*Callitris glauca*), a native softwood harvested in NSW and Queensland, is also used for glulam products. It is included together with hardwood glulam as it is also harvested in native forests, not plantations.

The properties and material composition of these products are defined in Table 1 and Table 2. Packaging is defined in Table 3.

Table 1: Properties of industry-average glulam included in this EPD

Properties	Softwood	Hardwood/Cypress
Density (kg per m^3)	621	674
Moisture content (dry basis)	12%	10.5%
Gross calorific value (MJ/kg)	20	20
Net calorific value (MJ/kg)	16.4	16.7
CO_2 sequestered (kg CO_2e)	1017	1118

Table 2: Composition of glulam products included in this EPD

Materials	Softwood	Hardwood/Cypress
Softwood (dry)	88.5%	0.0%
Hardwood or cypress pine (dry)	0.0%	90.2%
Polyurethane*	0.3%	0.3%
Phenol resorcinol formaldehyde (PRF)*	0.5%	0.03%
Water	10.7%	9.5%
Total	100.00%	100.00%

** Two resin types (polyurethane and PRF) are indicated as this EPD declares an industry-average product produced by multiple manufacturers. For a specific product from a specific manufacturer, only one resin type will be used. Check your manufacturer's safety data sheet or technical specification sheet to find out which resin type is used.*

Table 3: Packaging

Materials	Softwood (kg/m^3)	Hardwood/Cypress (kg/m^3)
Softwood gluts	5.71	0.33
Hardwood gluts	-	6.35
LDPE wrap	0.14	0.06
Plastic strapping	0.18	0.18
Steel strapping	-	0.07
Paper labels	-	0.002
Inks	0.05	0.05
Total	6.09	7.05

Representativeness

Market coverage: The data in this EPD are from detailed surveys of four of the six significant glulam plants in Australia. These plants collectively produced 19,052 m^3 of structural and decorative glulam in 2015/16, which is approximately 64% of total Australian production.

Temporal representativeness: Primary data were collected from participating sites for the 2015/16 Australian financial year (1 July 2015 to 30 June 2016).

Geographical and technological representativeness: The data are representative of the four sites surveyed, which collectively produce two-thirds of all Australian-produced glulam. Given that the glue-laminating step contributes a relatively small share to the total results (as shown in the 'Understanding the Life Cycle of Glulam' section), this EPD is representative of glulam manufactured from average timber grown and sawn in Australia. More detailed information can be found in the 'Variation in Results' section later in this EPD.

Industry Classifications

Product	Classification	Code	Category
All	UN CPC Ver.2	31600	Builders' joinery and carpentry of wood (including cellular wood panels, assembled parquet panels, shingles and shakes)*
All	ANZSIC 2006	1493	Veneer and Plywood Manufacturing

*This is the closest-matching category under the UN CPC v2 classification system. The description provided is not accurate for structural glulam.

LCA Calculation Rules

System Boundary

This EPD is of the 'cradle-to-gate' type with options. The options include the end-of-life stage, which is modelled through the use of scenarios.

Product stage			Con-struction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary
Raw material supply	Transport of raw materials	Manufacturing	Transport to customer	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to waste processing	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	X	X

Key: X = included in the EPD
MND = module not declared (such a declaration shall not be regarded as an indicator result of zero)

Production

The manufacturing process starts using kiln-dried softwood or hardwood, often rough sawn. All timber is accurately dressed to exact and uniform thickness. The dressed timber is then typically finger-jointed with adhesive into continuous lengths. Short-length products such as stair treads are not usually finger-jointed.

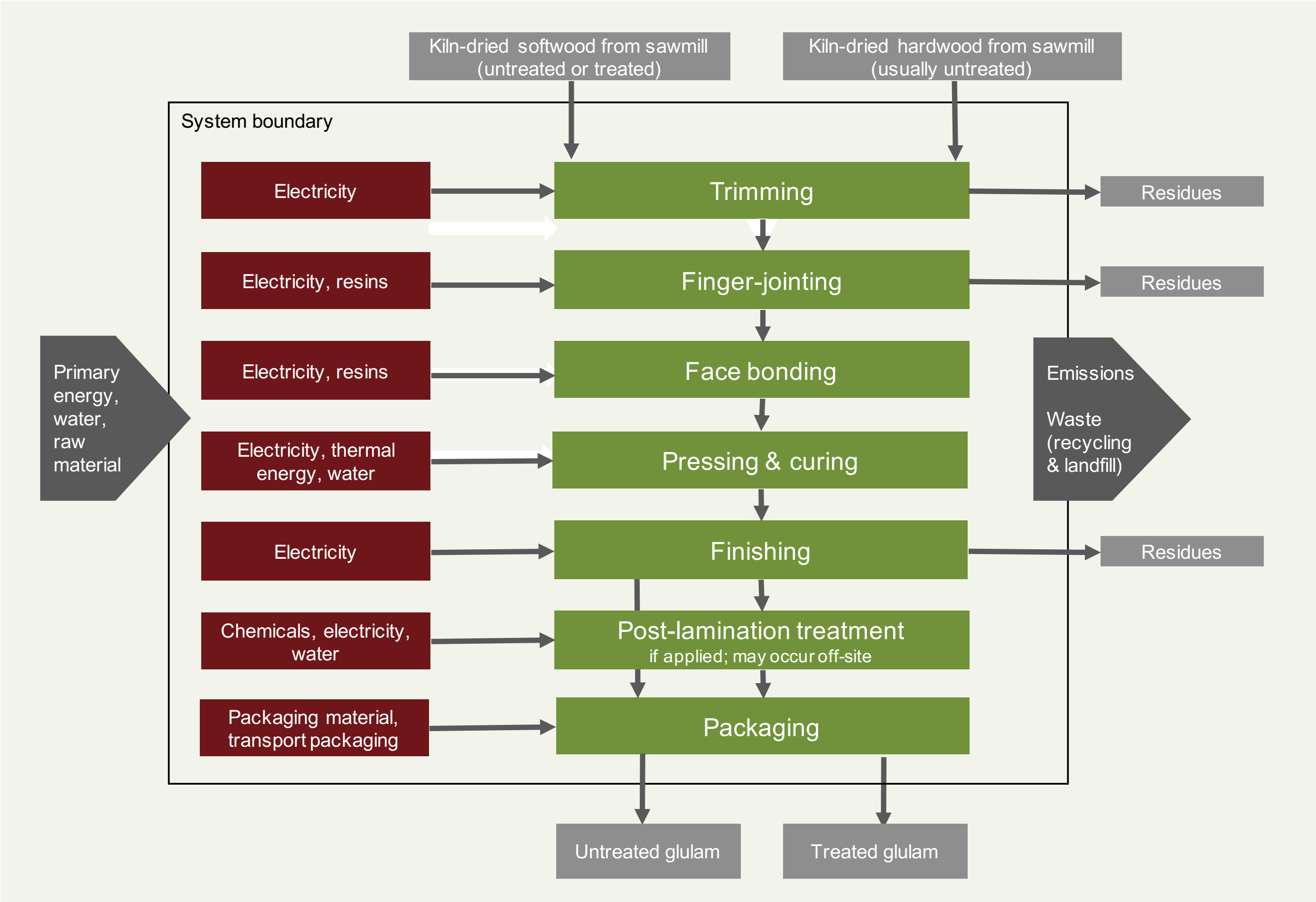
Glulam may be produced as standard straight dimensions or custom-made in various shapes and profiles. The dressed thickness of the timber to be laminated will depend on the application and species used. Curved members require thinner laminates. This EPD assumes straight members.

The sides of the dressed timber that will come into contact with each other are then spread with adhesive. The laminate is then clamped together under constant pressure until the glue has cured. Manufacturers using phenol resorcinol formaldehyde cure the glulam with heat while those using polyurethane cure the glulam at room temperature.

Polyurethane is used by three of the four manufacturers in this study, with phenol resorcinol formaldehyde (PRF) used by one manufacturer. As a result, industry-average glulam includes a mix of both polyurethane and PRF, even though only one resin type is used in any specific product.

For protection during storage and delivery, glulam sections may be separated with wood gluts, secured with plastic strapping and wrapped in plastic film. A weighted average is considered within this EPD.

Preservative treatment has been included separately to glulam production within this EPD. Environmental profiles for a range of common treatment options are included in the Durability and Preservative Treatment section within this EPD.



End-of-Life

When a wood product reaches the end of its useful life, it may either be reused, recycled, landfilled or combusted to produce energy. Landfill is currently the most common end-of-life route for wood products in Australia. Reuse is also common for structural glulam, as is often larger-dimension timber. All other scenarios are in use in certain regions (Forsythe Consultants 2007; National Timber Product Stewardship Group) and have been included within this EPD.

Each scenario assumes that 100% of the wood is sent to that scenario. To create an end-of-life mix for a given region or end use, the reader should take a weighted sum of these scenarios. Where no data are available, the 'landfill (typical)' scenario should be used for 100% of the waste.

Landfill

This EPD includes two scenarios for landfill, each with a different value for the degradable organic carbon fraction (DOCf) of wood. The two values are based on bioreactor laboratory research. This experimental work involves the testing of a range of waste types in reactors operated to obtain maximum methane yields. As the laboratory work optimises the conditions for anaerobic decay, the results can be considered as true estimates of the DOCf value that would apply over very long time horizons (Australian Government 2014a, p. 17).

- **Landfill (typical):** DOCf = 0.1% for softwood glulam and 0.0% for hardwood glulam. This is based on bioreactor laboratory research by Wang et al. (2011) for *Pinus radiata*, Australia's dominant plantation softwood species, and *Eucalyptus pilularis* (blackbutt), an important native hardwood species.

- **Landfill (NGA)**: DOCf = 10%. This is the value chosen for Australia's National Greenhouse Accounts (NGA) (Australian Government 2017). This is a reduction from the previous value of 23% (Australian Government 2014b) that was derived from early bioreactor laboratory research from the 1990s (e.g. Barlaz 1998) that investigated the degradability of wood tree branches ground to a fine powder under anaerobic conditions (Australian Government 2014a, p. 17). This DOCf value can be considered extremely conservative when compared to values from later research (as used in the typical scenario above) and effectively assumes that at least part of the wood waste is ground into a powder to accelerate degradation.

The impacts associated with the landfill are declared in module C4. All landfill gas that is combusted for energy recovery (module C4) is assumed to occur in a power plant with an electrical conversion efficiency of 36% (Australian Government 2014c, p. 189) and the resulting electricity receives a credit for offsetting average electricity from the Australian grid (module D) in line with EN 16485:2014 (Section 6.3.4.5).

Both landfill scenarios assume the following for carbon emissions:

- Of the gases formed from any degradation of wood in landfill, 50% is methane and 50% is carbon dioxide (Australian Government 2016, Table 43).
- All carbon dioxide is released directly to the atmosphere.
- 36% of the methane is captured, based on forecasted average methane capture in Australian landfills by 2020 (Hyder Consulting 2007). The year 2020 was chosen as landfill will take place in the future and this was the last year for which forecasts were available.
- Of this 36% captured, one quarter (9% of the total) is flared and three quarters (27% of the total) are used for energy recovery (Carre 2011).
- Of the 64% of methane that is not captured, 10% (6.4% of the total) is oxidised (Australian Government 2016, Table 43) and 90% (57.6%) is released to the atmosphere.
- In summary, for every kilogram of carbon converted to landfill gas, 71.2% is released as carbon dioxide and 28.8% is released as methane.

Energy recovery

This scenario includes shredding (module C3) and combustion with recovered energy offset against average thermal energy from natural gas (module D) in line with EN 16485:2014 (Section 6.3.4.5). Note that other options are also in use within Australia, including replacement of coal, replacement of electricity, and replacement of both electricity and thermal energy (via co-generation).

Reuse

The glulam product is assumed to be removed from a building manually and reused with no further processing (i.e. direct reuse). Transport and wastage are excluded and only one reuse cycle is considered. The second life is assumed to be the same (or very similar) to the first, meaning that a credit is given for production of 1 m^3 of primary structural in module D. The CO_2 sequestered and energy content of the wood are assumed to leave the system boundary at module C3 so that future product systems can also claim these without double-counting in line with EN 16485:2014 (Section 6.3.4.2). Any further processing, waste or transport would need to be modelled and included separately.

Recycling

Glulam may be recycled in many different ways. This scenario considers shredding and effectively downcycling into wood chips. Wood waste is chipped (module C3) and assigned credits relative to the avoided production of woodchips from virgin softwood, the primary material used for glulam (module D). In line with the reuse scenario, the CO_2 sequestered and energy content of the wood are assumed to leave the system boundary at C3 so that future product systems can also claim these without double-counting (EN 16485:2014, Section 6.3.4.2).

Key Assumptions

Wood input: The input into glue-laminating is assumed to be either average kiln-dried dressed softwood (see EPD S-P-00560) or average kiln-dried dressed hardwood (see EPD S-P-00561), depending on the final product. Datasets for the specific supply chain of each glulam manufacturer were not always available, making it necessary to apply the Australian average.

Energy: Thermal energy and transport fuels have been modelled as the Australian average (see thinkstep 2017 for documentation). Electricity for glulam production (modules A1-A3) has been modelled as a state-specific split based on the electricity consumption of the four manufacturers that contributed data to this study. Electricity for sawn softwood and sawn hardwood production has been modelled at the state-level using total cubic metres of production per state (see EPDs S-P-00560 and S-P-00561). Electricity at end-of-life (module C) has been modelled using an average Australian electricity mix as the location where the product reaches end-of-life is unknown.

Cut-off Criteria

Environmental impacts relating to personnel, infrastructure, and production equipment not directly consumed in the process are excluded from the system boundary as per the PCR (IEPDS 2017, Section 7.5.4). All other reported data were incorporated and modelled using the best available life cycle inventory data.

Allocation

Upstream data: For refinery products, allocation is done by mass and net calorific value. Inventories for electricity and thermal energy generation include allocation by economic value for some by-products (e.g. gypsum, boiler ash and fly ash). Allocation by energy is applied for co-generation of heat and power. For materials and chemicals, the allocation rule most suitable for the product is applied (see thinkstep 2014).

Co-products (e.g. sawdust): As the difference in economic value of the co-products is high (>25% as per EN 15804, Section 6.4.3.2), allocation has been done by economic value.

Background Data

Data for wood inputs (kiln-dried dressed softwood and kiln-dried dressed hardwood) come from EPD #1 for Softwood Timber (S-P-00560) and EPD #2 for Hardwood Timber (S-P-00561).

Data for all energy inputs, transport processes and raw materials are from GaBi Databases 2017 (thinkstep 2017). Most datasets have a reference year between 2013 and 2015 and all fall within the 10-year limit allowable for generic data under EN 15804 (Section 6.3.7).

EPD Results

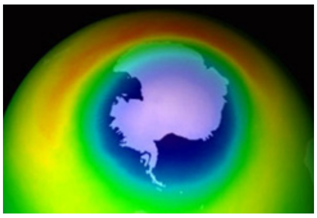
Note: These tables show the impacts associated with production and end-of-life. Any potential credits to future products from recycling or energy recovery are presented in the Other Environmental Information section.

Environmental Impact Indicators

An introduction to each environmental impact indicator is provided below.
The best-known effect of each indicator is listed to the right of its name.

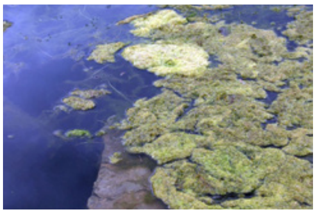
Global Warming Potential (GWP) → Climate Change
A measure of greenhouse gas emissions, such as carbon dioxide and methane. These emissions increase absorption of radiation emitted by the earth, intensifying the natural greenhouse effect. Contributions to GWP can come from either fossil or biogenic sources, e.g. burning fossil fuels or burning wood. GWP is reported as a total as well as being separated into biogenic carbon (GWPB) and fossil carbon (GWPF).

Ozone Depletion Potential (ODP) → Ozone Hole
A measure of air emissions that contribute to the depletion of the stratospheric ozone layer, causing higher levels of ultraviolet B (UVB) to reach the earth's surface with detrimental effects on humans, animals and plants.



Acidification Potential (AP) → Acid Rain
A measure of emissions that cause acidifying effects to the environment. Acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.

Eutrophication Potential (EP) → Algal Blooms
A measure of nutrient enrichment that may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. It includes potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P).



Photochemical Ozone Creation Potential (POCP) → Smog
A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O3), produced by the reaction of VOCs and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be harmful to human and ecosystem health and may also damage crops.

Abiotic Depletion Potential (ADP)→ Resource Consumption
The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Depletion of mineral resource elements (ADPE) and non-renewable fossil energy resources (ADPF) are reported separately.

Table 4: Environmental impacts, 1 m³ of glulam, softwood.

	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Parameter [Unit]	**A1-A3**	**C4**	**C4**	**C3**	**C3**	**C3**
GWP [kg CO_2-eq.]	-612	61.8	435	1,020	1,020	1,020
GWPF [kg CO_2-eq.]	380	58.1	58.2	6.30	6.30	0
GWPB [kg CO_2-eq.]	-992	3.76	377	1,020	1,020	1,020
ODP [kg CFC11-eq.]	4.02E-10	2.80E-11	2.80E-11	2.72E-13	2.72E-13	0
AP [kg SO_2-eq.]	1.80	0.183	0.208	0.0397	0.0397	0
EP [kg PO_4^{3-}-eq.]	0.378	0.0237	0.0299	0.00928	0.00928	0
POCP [kg C_2H_4-eq.]	0.812	0.0118	0.0845	0.00344	0.00344	0
ADPE [kg Sb-eq.]	1.51E-04	1.16E-05	1.16E-05	7.85E-08	7.85E-08	0
ADPF [MJ]	4,960	841	841	82.1	82.1	0

Table 5: Environmental impacts, 1 m³ of glulam, hardwood or cypress pine.

	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Parameter [Unit]	**A1-A3**	**C4**	**C4**	**C3**	**C3**	**C3**
GWP [kg CO_2-eq.]	-408	58.2	426	1,120	1,120	1,120
GWPF [kg CO_2-eq.]	527	58.2	58.4	6.83	6.83	0
GWPB [kg CO_2-eq.]	-935	-0.00614	368	1,120	1,120	1,120
ODP [kg CFC11-eq.]	1.57E-10	2.80E-11	2.80E-11	2.94E-13	2.94E-13	0
AP [kg SO_2-eq.]	3.41	0.184	0.208	0.0430	0.0430	0
EP [kg PO_4^{3-}-eq.]	0.687	0.0240	0.0300	0.0101	0.0101	0
POCP [kg C_2H_4-eq.]	4.37	0.0112	0.0828	0.00373	0.00373	0
ADPE [kg Sb-eq.]	5.00E-05	1.16E-05	1.16E-05	8.52E-08	8.52E-08	0
ADPF [MJ]	6,140	843	843	89.1	89.1	0

Resource Use

Table 6: Resource use, 1 m³ of glulam, softwood.

	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Parameter [Unit]	**A1-A3**	**C4**	**C4**	**C3**	**C3**	**C3**
PERE [MJ]	3,600	53.0	53.0	1.49	1.49	0
PERM [MJ]	10,200	0	0	-10,200	-10,200	-10,200
PERT [MJ]	13,800	53.0	53.0	-10,200	-10,200	-10,200
PENRE [MJ]	4,980	857	857	82.1	82.1	0
PENRM [MJ]	0	0	0	0	0	0
PENRT [MJ]	4,980	857	857	82.1	82.1	0
SM [kg]	0	0	0	0	0	0
RSF [MJ]	0	0	0	0	0	0
NRSF [MJ]	0	0	0	0	0	0
FW [m³]	2.43	0.00583	0.0474	9.01E-04	9.01E-04	0

__PERE__ = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; __PERM__ = Use of renewable primary energy resources used as raw materials; __PERT__ = Total use of renewable primary energy resources; __PENRE__ = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; __PENRM__ = Use of non-renewable primary energy resources used as raw materials; __PENRT__ = Total use of non-renewable primary energy resources; __SM__ = Use of secondary material; __RSF__ = Use of renewable secondary fuels; __NRSF__ = Use of non-renewable secondary fuels; __FW__ = Net use of fresh water

Table 7: Resource use, 1 m^3 of glulam, hardwood or cypress pine.

	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Parameter [Unit]	**A1-A3**	**C4**	**C4**	**C3**	**C3**	**C3**
PERE [MJ]	1,430	53.1	53.1	1.62	1.62	0
PERM [MJ]	11,200	0	0	-11,200	-11,200	-11,200
PERT [MJ]	12,700	53.1	53.1	-11,200	-11,200	-11,200
PENRE [MJ]	6,160	859	859	89.1	89.1	0
PENRM [MJ]	0	0	0	0	0	0
PENRT [MJ]	6,160	859	859	89.1	89.1	0
SM [kg]	0	0	0	0	0	0
RSF [MJ]	0	0	0	0	0	0
NRSF [MJ]	0	0	0	0	0	0
FW [m^3]	3.00	0.00562	0.0466	9.77E-04	9.77E-04	0

Waste and Output Flows

Table 8: Waste categories, 1 m^3 of glulam, softwood.

	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Parameter [Unit]	**A1-A3**	**C4**	**C4**	**C3**	**C3**	**C3**
HWD [kg]	2.11E-06	2.87E-06	2.87E-06	1.36E-07	1.36E-07	0
NHWD [kg]	34.9	623	514	5.66E-04	5.66E-04	0
RWD [kg]	0.0110	0.00608	0.00608	4.94E-06	4.94E-06	0
CRU [kg]	0	0	0	0	0	621
MFR [kg]	1.10	0	0	0	621	0
MER [kg]	0	0	0	621	0	0
EEE [MJ]	0	1.01	101	0	0	0
EET [MJ]	0	0	0	0	0	0

***HWD** = Hazardous waste disposed; **NHWD** = Non-hazardous waste disposed; **RWD** = Radioactive waste disposed;*
***CRU** = Components for reuse; **MFR** = Materials for recycling; **MER** = Materials for energy recovery;*
***EEE** = Exported electrical energy; **EET** = Exported thermal energy*

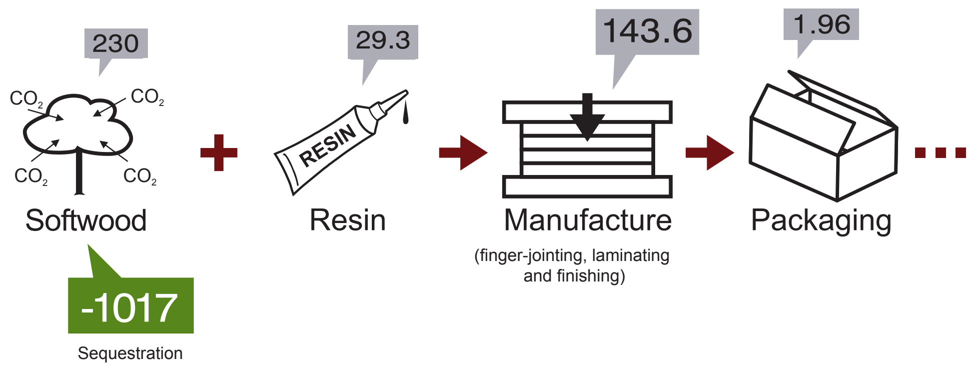
Table 9: Waste categories, 1 m^3 of glulam, hardwood or cypress pine.

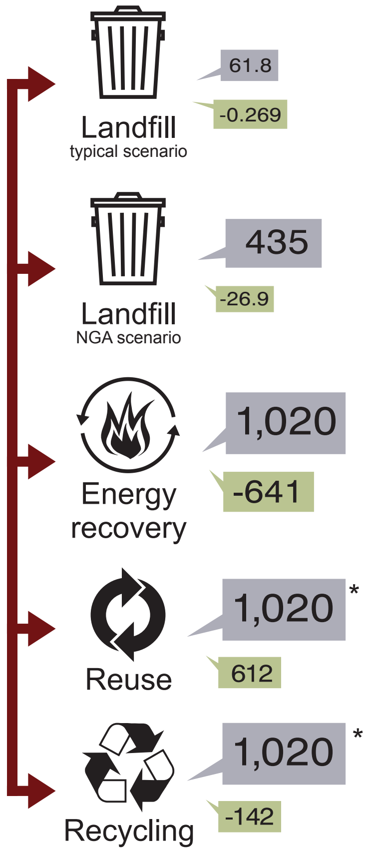
	Production	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Parameter [Unit]	**A1-A3**	**C4**	**C4**	**C3**	**C3**	**C3**
HWD [kg]	1.75E-06	2.99E-06	2.99E-06	1.48E-07	1.48E-07	0
NHWD [kg]	53.5	676	569	6.14E-04	6.14E-04	0
RWD [kg]	0.00801	0.00608	0.00608	5.35E-06	5.35E-06	0
CRU [kg]	0	0	0	0	0	674
MFR [kg]	0.0970	0	0	0	674	0
MER [kg]	0	0	0	674	0	0
EEE [MJ]	0	0	98.3	0	0	0
EET [MJ]	0	0	0	0	0	0

Understanding the Life Cycle of Glulam

Life cycle of Softwood glulam

Life cycle carbon footprint in kg CO_2-equivalent per m^3 of softwood glued-laminated timber (12% moisture content), including biogenic and fossil carbon



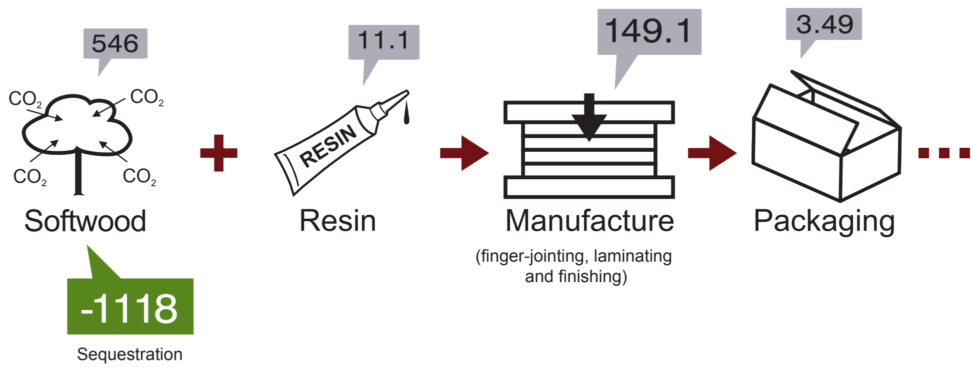


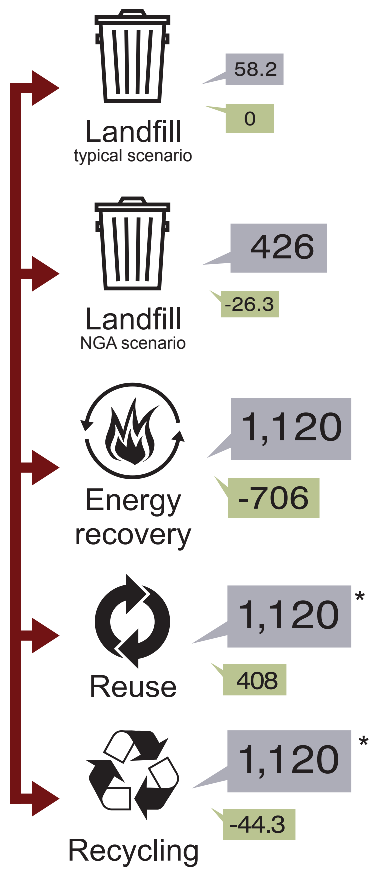
Where... Grey = environmental impact Green = impact avoided in next product system (credit)

* While carbon is not released directly through recycling, it is passed to another product system and is therefore counted as being released

Life cycle of Hardwood glulam

Life cycle carbon footprint in kg CO_2-equivalent per m^3 of hardwood glued-laminated timber (10% moisture content), including biogenic and fossil carbon





Where... Grey = environmental impact Green = impact avoided in next product system (credit)

* While carbon is not released directly through recycling, it is passed to another product system and is therefore counted as being released

Variation in Results

The variation between sites used to create the average shown in this EPD are given in Table 10 for the environmental impact indicators in modules A1-A3. Note that the site-level environmental profiles are calculated assuming an input of average Australian kiln-dried dressed wood, not each glulam manufacturer's supply chain. Full supply chain datasets were not available for all manufacturers.

Table 10: Inter-site variability for glulam (modules A1-A3).

	Softwood			Hardwood/Cypress		
Parameter [Unit]	**Min**	**Max**	**CV**	**Min**	**Max**	**CV**
GWP [kg CO_2-eq.]	-12.3%	+19.0%	±12.8%	-110.8%	+17.1%	±49.9%
GWPF [kg CO_2-eq.]	-16.4%	+9.4%	±12.1%	-10.0%	+16.2%	±9.4%
GWPB [kg CO_2-eq.]	-11.2%	+17.9%	±12.0%	-57.5%	+8.1%	±25.7%
ODP [kg CFC11-eq.]	-76.7%	+66.4%	±66.4%	-14.9%	+359.8%	±159.1%
AP [kg SO_2-eq.]	-15.3%	+15.4%	±13.7%	-9.4%	+13.8%	±8.3%
EP [kg PO_4^{3}-eq.]	-10.4%	+11.5%	±9.7%	-4.7%	+14.9%	±7.8%
POCP [kg C_2H_4-eq.]	-6.7%	+4.3%	±4.5%	-3.1%	+4.0%	±2.7%
ADPE [kg Sb-eq.]	-12.1%	+11.3%	±9.5%	-7.2%	+90.5%	±37.0%
ADPF [MJ]	-21.9%	+14.5%	±16.3%	-5.6%	+28.9%	±13.4%

***Min** = (minimum - average) / average; **Max** = (maximum - average) / average;*
***CV** = coefficient of variation = standard deviation / average*

Carbon Dioxide Sequestration

During growth, trees absorb carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis and convert this into carbon-based compounds that constitute various components of a tree, including wood. On average, half the dry weight of all wood is made up of the element carbon (Gifford 2000).

All major Australian production forests and plantations are independently certified to one, or both, of the internationally recognised forest management certification systems: the Australian Standard for Sustainable Forest Management (AS 4708), which is recognised under the Programme for the Endorsement of Forest Certification (PEFC), and/or one of the Forest Stewardship Council's (FSC®) interim forest management standards. It is therefore appropriate to include biogenic CO_2 sequestration in this EPD in line with EN 16485 (Section 6.3.4.2).

Other Environmental Information

Module D: Recycling, Reuse and Recovery Potentials

Table 11: Module D, 1 m³ of glulam, softwood.

Parameter [Unit]	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Environmental Impact					
GWP [kg CO_2-eq.]	-0.269	-26.9	-641	-142	612
GWPF [kg CO_2-eq.]	-0.269	-26.9	-643	-135	-380
GWPB [kg CO_2-eq.]	-5.50E-06	-5.50E-04	1.59	-6.25	992
ODP [kg CFC11-eq.]	-7.69E-15	-7.69E-13	-6.48E-12	-1.18E-11	-4.02E-10
AP [kg SO_2-eq.]	-0.00119	-0.119	0.0144	-1.04	-1.80
EP [kg PO_4^{3-}-eq.]	-1.00E-04	-0.01000	-0.0202	-0.241	-0.378
POCP [kg C_2H_4-eq.]	-6.19E-05	-0.00619	0.119	-0.429	-0.812
ADPE [kg Sb-eq.]	-2.00E-08	-2.00E-06	-3.90E-05	-2.57E-05	-1.51E-04
ADPF [MJ]	-3.07	-307	-11,300	-1,730	-4,960
Resource Use					
PERE [MJ]	-0.345	-34.5	-1.88	-2,510	-3,600
PERM [MJ]	0	0	0	0	-10,200
PERT [MJ]	-0.345	-34.5	-1.88	-2,510	-13,800
PENRE [MJ]	-3.07	-307	-11,300	-1,740	-4,980
PENRM [MJ]	0	0	0	0	0
PENRT [MJ]	-3.07	-307	-11,300	-1,740	-4,980
SM [kg]	0	0	0	621	621
RSF [MJ]	0	0	10,200	0	0
NRSF [MJ]	0	0	0	0	0
FW [m^3]	-0.00159	-0.159	-0.00711	-0.533	-2.43
Wastes and Outputs					
HWD [kg]	-4.05E-10	-4.05E-08	-8.54E-07	-5.09E-07	-2.11E-06
NHWD [kg]	-7.83E-04	-0.0783	29.9	-17.8	-34.9
RWD [kg]	-3.78E-07	-3.78E-05	-2.77E-04	-6.26E-04	-0.0110
CRU [kg]	0	0	0	0	0
MFR [kg]	0	0	0	0	-1.10
MER [kg]	0	0	0	0	0
EEE [MJ]	0	0	0	0	0
EET [MJ]	0	0	0	0	0

Table 12: Module D, 1 m^3 of structural glulam, hardwood or cypress pine.

Parameter [Unit]	Landfill (typical)	Landfill (NGA)	Energy recovery	Reuse	Recycling
Environmental Impact					
GWP [kg CO_2-eq.]	0	-26.3	-706	-44.3	408
GWPF [kg CO_2-eq.]	0	-26.3	-708	-36.5	-527
GWPB [kg CO_2-eq.]	0	-5.37E-04	1.75	-7.81	935
ODP [kg CFC11-eq.]	0	-7.51E-13	-7.14E-12	-3.43E-11	-1.57E-10
AP [kg SO_2-eq.]	0	-0.116	0.0137	-0.689	-3.41
EP [kg PO_4^{3}-eq.]	0	-0.00978	-0.0227	-0.136	-0.687
POCP [kg C_2H_4-eq.]	0	-0.00604	0.131	-0.271	-4.37
ADPE [kg Sb-eq.]	0	-1.95E-06	-4.29E-05	-1.85E-05	-5.00E-05
ADPF [MJ]	0	-300	-12,400	-419	-6,140
Resource Use					
PERE [MJ]	0	-33.7	-2.07	-2,410	-1,430
PERM [MJ]	0	0	0	0	-11,200
PERT [MJ]	0	-33.7	-2.07	-2,410	-12,700
PENRE [MJ]	0	-300	-12,400	-424	-6,160
PENRM [MJ]	0	0	0	0	0
PENRT [MJ]	0	-300	-12,400	-424	-6,160
SM [kg]	0	0	0	674	674
RSF [MJ]	0	0	11,200	0	0
NRSF [MJ]	0	0	0	0	0
FW [m^3]	0	-0.155	-0.00784	-0.588	-3.00
Wastes and Outputs					
HWD [kg]	0	-3.95E-08	-9.41E-07	-7.20E-06	-1.75E-06
NHWD [kg]	0	-0.0765	32.8	-3.95	-53.5
RWD [kg]	0	-3.69E-05	-3.05E-04	-0.00219	-0.00801
CRU [kg]	0	0	0	0	0
MFR [kg]	0	0	0	0	-0.0970
MER [kg]	0	0	0	0	0
EEE [MJ]	0	0	0	0	0
EET [MJ]	0	0	0	0	0

Durability and Preservative Treatment

As described in the Scope section, the body of the EPD covers untreated glulam. To calculate an environmental profile for treated softwood glulam, please add the values for the appropriate treatment type from either Table 13 or Table 14 to the A1-A3 values in Table 4. For hardwood glulam, please add the values for the appropriate treatment type from Table 15 to the A1-A3 values in Table 5.

AS/NZS 1604.5:2012 Specification for preservative treatment Glued laminated timber products allows for the use of wood that is already treated or post- treatment (envelope treatment) to the appropriate hazard class with allowable preservative.

Table 13: Environmental data for preservative treatment of softwood (non-copper treatments), per m^3 of treated glulam.

Parameter [Unit]	Bifenthrin [H2]	Bifenthrin [H2F]	LOSP (permethrin) [H2]	LOSP (permethrin) [H2F]	LOSP (azole + permethrin) [H3]
Environmental Impact					
GWP [kg CO_2-eq.]	11.2	10.9	12.1	11.4	59.0
GWPF [kg CO_2-eq.]	11.2	10.9	12.1	11.4	58.9
GWPB [kg CO_2-eq.]	0.00527	0.00307	0.0114	0.00679	0.0892
ODP [kg CFC11-eq.]	1.77E-12	1.14E-12	3.59E-12	2.25E-12	1.51E-10
AP [kg SO_2-eq.]	0.0478	0.0470	0.0504	0.0486	0.158
EP [kg PO_4^{3-}-eq.]	0.00409	0.00400	0.00439	0.00418	0.0149
POCP [kg C_2H_4-eq.]	0.0386	0.0230	0.0191	0.0123	6.74
ADPE [kg Sb-eq.]	3.14E-05	1.82E-05	1.02E-04	6.09E-05	2.02E-04
ADPF [MJ]	151	141	165	151	2,070
Resource Use					
PERE [MJ]	14.2	22.0	19.9	16.3	17.6
PERM [MJ]	0	0	0	0	0
PERT [MJ]	14.2	22.0	19.9	16.3	17.6
PENRE [MJ]	151	366	286	167	232
PENRM [MJ]	0	0	0	0	0
PENRT [MJ]	151	366	286	167	232
SM [kg]	0	0	0	0	0
RSF [MJ]	0	0	0	0	0
NRSF [MJ]	0	0	0	0	0
FW [m^3]	0.0701	0.114	0.106	0.0699	0.0902
Wastes and Outputs					
HWD [kg]	2.88E-08	1.86E-07	4.76E-04	5.24E-08	3.12E-04
NHWD [kg]	0.0384	1.46	0.165	0.0528	0.118
RWD [kg]	2.62E-04	0.00335	0.00214	7.16E-04	0.00141
CRU [kg]	0	0	0	0	0
MFR [kg]	0	0	0	0	0
MER [kg]	4.00	5.00	6.00	7.00	8.00
EEE [MJ]	0	0	0	0	0
EET [MJ]	0	0	0	0	0

Table 14: Environmental data for preservative treatment of softwood (copper treatments), per m³ of treated glulam.

Parameter [Unit]	Copper + DDAX [H3]	Copper azole [H3]	Copper azole [H4]	CCA [H3]	CCA [H4]
Environmental Impact					
GWP [kg CO_2-eq.]	17.8	15.3	19.2	32.5	25.1
GWPF [kg CO_2-eq.]	17.8	15.2	19.2	32.0	24.7
GWPB [kg CO_2-eq.]	0.0478	0.0314	0.0570	0.527	0.350
ODP [kg CFC11-eq.]	8.75E-11	5.74E-11	1.04E-10	8.56E-10	5.68E-10
AP [kg SO_2-eq.]	0.326	0.229	0.379	0.378	0.266
EP [kg PO_4^{3-}-eq.]	0.00678	0.00578	0.00734	0.0120	0.00925
POCP [kg C_2H_4-eq.]	0.0146	0.0104	0.0170	0.0179	0.0127
ADPE [kg Sb-eq.]	2.90E-04	1.90E-04	3.46E-04	0.00361	0.00239
ADPF [MJ]	281	228	310	395	306
Resource Use					
PERE [MJ]	33.8	21.1	13.2	13.2	13.2
PERM [MJ]	0	0	0	0	0
PERT [MJ]	33.8	21.1	13.2	13.2	13.2
PENRE [MJ]	2,090	316	129	129	129
PENRM [MJ]	0	0	0	0	0
PENRT [MJ]	2,090	316	129	129	129
SM [kg]	0	0	0	0	0
RSF [MJ]	0	0	0	0	0
NRSF [MJ]	0	0	0	0	0
FW [m^3]	0.223	0.114	0.0610	0.0610	0.0610
Wastes and Outputs					
HWD [kg]	3.47E-07	5.67E-04	1.63E-08	1.63E-08	1.63E-08
NHWD [kg]	0.313	0.190	0.0300	0.0300	0.0300
RWD [kg]	0.00762	0.00255	1.47E-05	1.47E-05	1.47E-05
CRU [kg]	0	0	0	0	0
MFR [kg]	0	0	0	0	0
MER [kg]	9.00	10.00	11.0	12.0	13.0
EEE [MJ]	0	0	0	0	0
EET [MJ]	0	0	0	0	0

Table 15: Environmental data for preservative treatment of hardwood glulam, per m³ of treated glulam.

Parameter [Unit]	Boron [H1]	ACQ [H3]	Copper azole [H3]	CCA [H4]	CCA [H5/6]
Environmental Impact					
GWP [kg CO_2-eq.]	10.8	27.5	21.5	14.5	24.4
GWPF [kg CO_2-eq.]	10.8	27.4	21.5	14.4	24.0
GWPB [kg CO_2-eq.]	0.00243	0.121	0.0717	0.0973	0.333
ODP [kg CFC11-eq.]	7.11E-12	6.71E-10	1.31E-10	1.58E-10	5.41E-10
AP [kg SO_2-eq.]	0.0504	0.126	0.465	0.107	0.256
EP [kg PO_4^{3-}-eq.]	0.00442	0.0128	0.00824	0.00537	0.00899
POCP [kg C_2H_4-eq.]	0.00268	0.00849	0.0208	0.00528	0.0122
ADPE [kg Sb-eq.]	2.97E-04	0.0395	4.35E-04	6.65E-04	0.00228
ADPF [MJ]	135	357	357	178	297
Resource Use					
PERE [MJ]	13.3	49.3	23.2	32.4	46.1
PERM [MJ]	0	0	0	0	0
PERT [MJ]	13.3	49.3	23.2	32.4	46.1
PENRE [MJ]	135	381	365	648	1,020
PENRM [MJ]	0	0	0	0	0
PENRT [MJ]	135	381	365	648	1,020
SM [kg]	0	0	0	0	0
RSF [MJ]	0	0	0	0	0
NRSF [MJ]	0	0	0	0	0
FW [m^3]	0.0683	0.302	0.128	0.178	0.261
Wastes and Outputs					
HWD [kg]	2.28E-08	4.44E-07	7.14E-04	3.87E-07	6.51E-07
NHWD [kg]	0.0477	8.64	0.232	3.16	5.40
RWD [kg]	6.14E-05	0.00964	0.00320	0.00730	0.0125
CRU [kg]	0	0	0	0	0
MFR [kg]	0	0	0	0	0
MER [kg]	0	1.000	2.00	3.00	4.00
EEE [MJ]	0	0	0	0	0
EET [MJ]	0	0	0	0	0

Water Consumption

The FW indicator in the EPD results tables reports consumption (i.e. net use) of 'blue water' (which includes river water, lake water and ground water). This indicator deliberately excludes consumption of 'green water' (rain water).

PCR 2012:01 (Section 16.1) states that all water loss from a drainage basin is considered consumption, including any net loss of rain water. According to the PCR, net loss should be interpreted as any additional water loss beyond what would occur in the original, natural system. For plantation softwood forestry, the natural system might be a native forest or a grassland (Quinteiro et al. 2015). Previous work by CSIRO calculated the difference in water flow between plantation forests and a base case land use (pasture) (CSIRO 2009).

Table 16 reports green water consumption calculated by CSIRO using 2005-08 data. These values have not been updated and are now reported here rather than in the main results tables to reflect their uncertainty. At the time of writing, there is no internationally agreed method for calculating green water consumption due to evapotranspiration relative to a hypothetical natural state (Manzardo et al. 2016). As such, different calculation methods may yield significantly different results, introducing a high level of uncertainty.

The reader should also be aware that water consumption does not account for relative water stress in the catchment(s) where the forest is located, meaning that it provides no information about the potential impacts of any water consumption that does occur.

Table 16: Green water consumption estimates for modules A1-A3 from CSIRO (2009).

	Sawn, kiln-dried softwood	**Dressed, kiln-dried softwood**
Parameter [Unit]	A1-A3	A1-A3
Green water consumption in forest [m^3]	414	1,290

Timber & Forest Certification

Many Australian timber and reconstituted wood products are certified to a forest certification scheme. This certification is an independent auditing process which provides:

- Assurance that the timber is from well-managed forests certified to internationally and nationally accepted forest management standards
- Assurance that the timber is from legally harvested sources
- Chain of custody (CoC) certification extending from the forest to the end user, which is traceable throughout the supply chain.

Two schemes apply to Australian wood production forests. One is administered by the Australian Forestry Standard Ltd (AFS). The AFS scheme is also endorsed by the international Programme for Endorsement of Forest Certification (PEFC). The other scheme is administered by the Forest Stewardship Council (FSC®) Australia.

If a Green Star project elects to use the timber credit as part of their Green Star submission, the Green Building Council of Australia recognises PEFC-endorsed forest certification schemes (such as the Australian Forest Certification Scheme, AFCS) as well as FSC®. Compliance with the chain of custody certification rules of either forest certification scheme for at least 95% by value of timber products used in the project will meet the requirements for this credit point (GBCA 2014).

As of 2017, there are more than 26.7 million hectares of native and plantation forests certified under AFS (AFS 2017) and 1.2 million hectares certified under FSC® interim national standards (FSC 2017).

In addition, two of the Australian glulam manufacturers' premises listed in this EPD are CoC certified, and can therefore supply certified products.

Land Use and Biodiversity

Like other land uses, forestry operations for timber and wood production can have both positive and negative effects on biodiversity. However, as biodiversity varies considerably by region and as data are often limited, assessing potential biodiversity impacts within LCA is challenging.

An Australian study (Turner *et al*. 2014) demonstrated a new method – BioImpact – to discern the biodiversity impacts of different land uses. A trial of this method was conducted using case studies in three different regions and four production systems in New South Wales: native hardwood forestry, plantation softwood forestry, mixed cropping and rangeland grazing. Managed forestry resulted in biodiversity impacts equivalent to or better than those of cropping/grazing systems.

Indoor Environment Quality – Formaldehyde Emissions Minimisation

Glulam products in Australia are manufactured using either polyurethane (PU) resin, which is formaldehyde-free, or phenol resorcinol formaldehyde (PRF) resin.

Formaldehyde is a colourless, strong-smelling gas that occurs naturally in the environment. It is present in the air that we breathe at natural background levels of about 0.03 parts per million (ppm) and up to 0.08 ppm in outdoor urban air (EWPAA 2012). Formaldehyde is used as an ingredient in synthetic resins, industrial chemicals, preservatives, and in the production of paper, textiles, cosmetics, disinfectants, medicines, paints, varnishes and lubricants.

Once cured, phenol resorcinol formaldehyde emits extremely low levels of formaldehyde. It will meet the requirements for classification of emissions class Super E0 as defined in an industry-wide formaldehyde testing and labelling program run by the Engineered Wood Products Association of Australasia. This formaldehyde emission class is detailed in Table 17.

Table 17: Formaldehyde emission classes.

Emission class	Emission limit (mg/litre)	Emission limit (ppm)*	Adhesive associated with emission class
Super E0 / (equivalent to F☆☆☆☆)	Less than or equal to 0.3	Less than or equal to 0.03	Phenol resorcinol formaldehyde

** Based on a test chamber volume of 10 litre, zero airflow during the 24 hour test cycle, molecular weight of formaldehyde 30.03 and the number of microlitres of formaldehyde gas in 1 micromole at 101KPa and 298K.*

Glulam with formaldehyde emissions less than or equal to Super E0 (which applies to all glulam producers listed in this EPD) are compliant with the most stringent Green Star Formaldehyde credit for engineered wood products.

References

AFS. (2017) Australian Forestry Standard Ltd. Available at http://www.forestrystandard.org.au/

AS 1604.1:2010. *Specification for preservative treatment—Part 1: Sawn and round timber.* Standards Australia.

Australian Government. (2014a). *National Inventory Report 2012, Volume 3: Australia data for waste, recalculations, improvements and Kyoto Protocol accounting requirements*. Australian National Greenhouse Accounts. Available at http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/national-inventory-report-2012

Australian Government. (2014b). *National Greenhouse Accounts Factors* - December 2014. Department of Environment.

Australian Government. (2014c). *Technical Guidelines for the Estimation of Greenhouse Gas Emissions by Facilities in Australia.* Department of Environment.

Australian Government. (2015). *Forest Certification in Australia.* Department of Agriculture. Available at http://www.agriculture.gov.au/forestry/australias-forests/certification

Australian Government. (2016). *National Greenhouse Accounts Factors – August 2016*. Department of Environment.

Barlaz, M. (1998). Carbon storage during biodegradation of municipal solid waste components in laboratory scale landfills. *Global Biogeochemical Cycles*, 12 (2), 373–380.

Blue Environment. (2013). *Analysis of landfill survey data*. Final report prepared for Waste Management Association of Australia. Available at http://www.environment.gov.au/protection/national-waste-policy/publications/analysis-landfill-survey-data

Carre, A. (2011). *A Comparative Life Cycle Assessment of Alternative Constructions of a Typical Australian House Design*. Melbourne: Forest & Wood Products Australia. Available at http://www.fwpa.com.au/images/marketaccess/PNA147-0809_Research_Report_Comparative-LCA_0.pdf

CSIRO. (2009). (Prepared by Tucker, S.N.; Tharumarajah, A.; May, B.; England, J.; Paul, K.; Hall, M.; Mitchell, P.; Rouwette, R.; Seo, S. and Syme, M.) *Life Cycle Inventory of Australian Forestry and Wood Products*. Prepared by the Commonwealth Scientific and Industrial Research Organisation on behalf of Forest and Wood Products Australia. Project number PNA008-0708.

EN 15804:2012+A1:2013. *Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products.* Brussels: European Committee for Standardization.

EN 16449:2014. *Wood and wood-based products – Calculation of the biogenic carbon content of wood and conversion to carbon dioxide.* Brussels: European Committee for Standardization.

EN 16485:2014. *Round and sawn timber — Environmental Product Declarations — Product category rules for wood and wood-based products for use in construction.* Brussels: European Committee for Standardization.

EWPAA. (2012). *Facts About Formaldehyde Emissions from EWPAA Certified Products*. Engineered Wood Products Association of Australasia. Available at http://www.ewp.asn.au/library/downloads/ewpaa_formaldehyde_facts.pdf

Forsythe Consultants. (2007). *Mapping the Timber Waste Stream from Building Demolition.* Available at http://www.timberstewardship.org.au/images/pdf_documents/demolition_waste_barriers_final.pdf

GBCA. (2014). *Revised Timber Credit*. Green Building Council of Australia. Available at https://www.gbca.org.au/green-star/technical-support/materials-category/revised-timber-credit/2693.htm

Gifford, R. (2000). *Carbon Contents of Above-Ground Tissues of Forest and Woodland Trees.* Technical report No. 22. National Carbon Accounting Scheme. Australian Greenhouse Office. Available at http://pandora.nla.gov.au/pan/23322/20020220-0000/www.greenhouse.gov.au/ncas/files/pdfs/tr22final.pdf

GLTAA (2017). *Historical Review*. Glued Laminated Timber Association of Australia. Available at: http://www.gltaa.com.au/historical-review/

Hyder Consulting Group. (2007). *Review of Methane Recovery and Flaring from Landfills.* Australian Greenhouse Office, Department of Environment and Water Resources.

IEPDS. (2015). *PCR 2012:01, Construction products and Construction services, Version 2.0, 2015-03-03.* Stockholm: International EPD® System. Available at: http://www.environdec.com/en/PCR/Detail/?Pcr=8098

ISO 14025:2006. *Environmental labels and declarations — Type III environmental declarations - Principles and procedures.* Geneva: International Organization for Standardization.

Manzardo, A., Mazzi, A., Loss, A., Butler, M., Williamson, A. and Scipioni, A. (2016). *Lessons learned from the application of different water footprint approaches to compare different food packaging alternatives.* Journal of Cleaner Production, 112, pp. 4657-4666.

National Timber Product Stewardship Group. (2015). Available at www.timberstewardship.org.au

Quinteiro, P., Dias, A.C., Silva, M., Ridoutt, B.G., Arroja, L. (2015). *A contribution to the environmental impact assessment of green water flows.* Journal of Cleaner Production, 93, pp. 318-329

thinkstep. (2017). *GaBi Database 2017 Life Cycle Inventory Documentation*. Leinfelden-Echterdingen, Germany: thinkstep AG. URL: http://database-documentation.gabi-software.com/support/gabi/gabi-database-2017-lci-documentation/

Turner, P., Ximenes, F., Penman, T., Law, B., Waters, C., Mo, M. and Brock, P. (2014). *Accounting for biodiversity in Life Cycle Impact Assessments of forestry and agricultural systems – the BioImpact metric.* Research report for Forest & Wood Products Australia Limited. Available at http://www.fwpa.com.au

Wang, W., Padgett, J., De La Cruz, F. and Barlaz, M. (2011). *Wood biodegradation in laboratory-scale landfills*. *Environmental Science & Technology,* 45(16), pp. 6864-6871.

WoodSolutions. (2012). *Timber Service Life Design Guide*. Available at https://www.woodsolutions.com.au/Articles/Resources/Timber-Service-life-design

WoodSolutions. (2015). *Timber Preservation.* Available at http://www.woodsolutions.com.au/Articles/Resources/Timber-Preservation

Ximenes, F., Brooks, P., Wilson, C. and Giles, D. (2013). *Carbon Storage in Engineered Wood Products in Landfills*. Forest and Wood Products Australia. Available at http://www.fwpa.com.au/rd-and-e/processing/181-carbon-storage-in-engineered-wood-products-in-landfills.html