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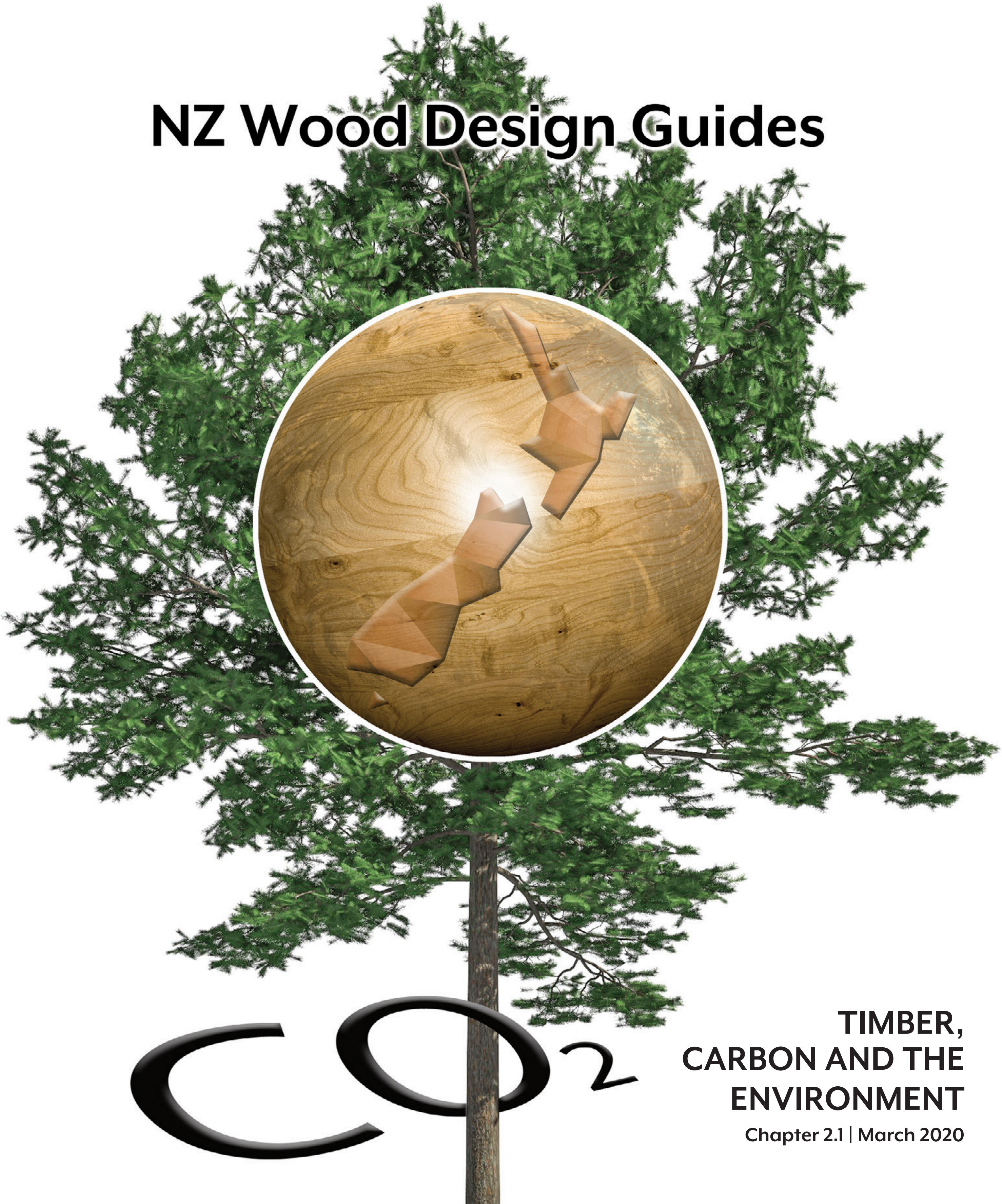
NZ Wood Design Guides



TIMBER, CARBON AND THE ENVIRONMENT

Chapter 2.1 | March 2020

NZ Wood Design Guides

A growing suite of information, technical and training resources, the Design Guides have been created to support the use of wood in the design and construction of the built environment.

Each title has been written by experts in the field and is the accumulated result of years of experience in working with wood and wood products.

Some of the popular topics covered by the Design Guides include:

- Timber, Carbon and the Environment
- Seismic Design of Timber Buildings
- Holes, Notches and Cutouts
- Post and Beam Buildings
- Working Safely with Prefabricated Timber
- Structural Forms and Exemplars

To discover more, please visit http://nzwooddesignguides.wpma.org.nz

NZ Wood Design Guides is a Wood Processors and Manufacturers Association (WPMA) initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction.

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CONTENTS

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1. INTRODUCTION

"When someone invents a material that is renewable, reusable, organic, biodegradable, whose production cleans the air and water, sequesters carbon, creates oxygen, provides habitat for us and other species, gives us a material that is strong, light, diverse, versatile, beautiful, ubiquitous and inexpensive then I'll embrace it. Until then, I'll use wood whenever I can."

(Peter Moonen, Canadian Wood Council)

The environmental credentials of wood are sometimes obvious and need little explanation. As an organic material, sourced from a biological resource – trees, it is the only renewable mainstream construction material. As we face immense global challenges of climate change, increasing urbanisation, population rise and resource depletion, wood clearly has a part to play in the solutions we need for more sustainable construction.

Given the overarching and urgent challenge of reducing greenhouse gas emissions to combat global climate change, this guide explores the environmental sustainability dimension of wood, with a specific focus on the Carbon benefits of using wood in construction.

Being 'renewable' and 'low Carbon' are the most cited environmental benefits of wood, however assessing the carbon benefits of wood, as well its broader environmental sustainability, is a complex matter with opportunities for confusion and misinterpretation.

For this reason, this guide looks at the meaning of the terms 'Carbon footprint', 'sequestered Carbon', 'Life Cycle Assessment' and others. It examines how the Carbon footprints of wood and buildings made from wood are evaluated, and how to make fair comparisons with other materials. It provides readers with useful information to make their own assessments on the Carbon credentials of wood, and it provides context around issues related to the use of wood in construction, such as the sustainability of the forestry sector, the use of glues and treatments in wood products, and the Carbon emissions from transporting wood products.

Finally, it explores how the construction industry can recognise the Carbon benefits of wood in sustainability ratings tools and indicators, and how regulatory drivers could be used to promote the use of wood as a strategy to reduce the Carbon emissions from construction.

2. BACKGROUND

2.1 SUSTAINABLE DEVELOPMENT

The term 'sustainable development' was defined by the United Nations 1987 report "Our common future", also known as the Brundtland report:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The concept of the 'triple bottom line' was introduced in the early 1990s to expand the traditional reporting framework (of revenues and expenses) to take into account social and environmental impacts in addition to financial performance.

A sustainable solution is one where social, environmental and economic needs of future generations are not compromised.

The words "sustainability" and "sustainable" are overused, and arguments can be made for or against the relative sustainability of any particular process/action product, making it difficult to have confidence in any particular claim.

Particularly for environmental impacts, hidden effects that might not seem obvious and are hard to measure can reduce the sustainability of a solution.

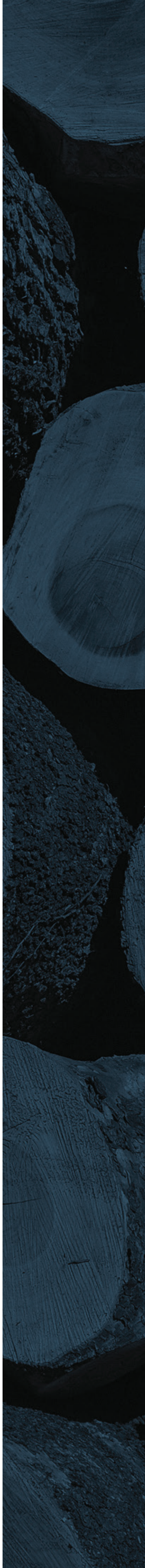
More recently, the concept of sustainability can be viewed in the context of the United Nations Sustainable Development Goals (SDGs), adopted by all 193 United Nations member states, including New Zealand, in 2015.

The SDGs cover a broad range of sustainable development issues, including ending poverty and hunger, improving health and education, combating climate change and protecting forests.

Figure 1: The United Nations Sustainable Development Goals

Within the 17 goals there are 169 targets that all UN member states must use to frame their domestic and international agendas and political policies for the next 15 years. Member states will be expected to tailor the targets for each goal, based on current statistics, to ensure progress continues.

The Global Meeting 'Sustainable Wood for a Sustainable World ' (SW4SW) was held in October 2017 by the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the Centre for International Forestry Research (CIFOR), the World Bank, the World Wildlife Fund (WWF) and others. They identified that sustainable wood value chains are relevant for all 17 SDGs, and especially for SDG8, SDG12, SDG13 and SDG15. To promote and support the use of sustainable wood across all sectors, including construction, the SW4SW was adopted in May 2018 as a Joint Initiative of the Collaborative Partnership on Forests (CPF) lead by FAO and its partners.



2.2 CLIMATE CHANGE

Anthropogenic climate change is widely seen as the greatest global challenge humanity faces. The central aim of the 2016 Paris climate accord is to accelerate and intensify actions and investments needed to keep a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. Without big changes to the status quo, modelling suggests we are heading for 3.5°C rise within that timeframe.

The damaging effects of climate change are already being seen throughout the world, in the form of droughts, increased frequency of high intensity storms, massive losses in polar ice coverage and glaciers, and increasingly common bush and forest fires.

What part can we play in the building and construction sector? Steel and cement are each responsible for between 5-8% of global emissions of Carbon Dioxide (CO_2), the most significant greenhouse gas causing global warming. Much of this material goes into the construction of buildings, specified by designers and used by contractors. The sector has a responsibility to focus on reducing greenhouse gas emissions by using less of these Carbon intensive materials, either by increasing how efficiently they are used, or by substituting them for lower Carbon alternatives, such as wood.

2.3 CARBON EMISSIONS IN A NEW ZEALAND CONTEXT

A breakdown of New Zealand's greenhouse gas emissions by production shows agriculture is the dominant industry, primarily due to methane emissions from dairy cattle and other farmed animals. Consequently, a pragmatic approach to reducing emissions could be considered to focus on agriculture, in preference to other sectors of the economy.

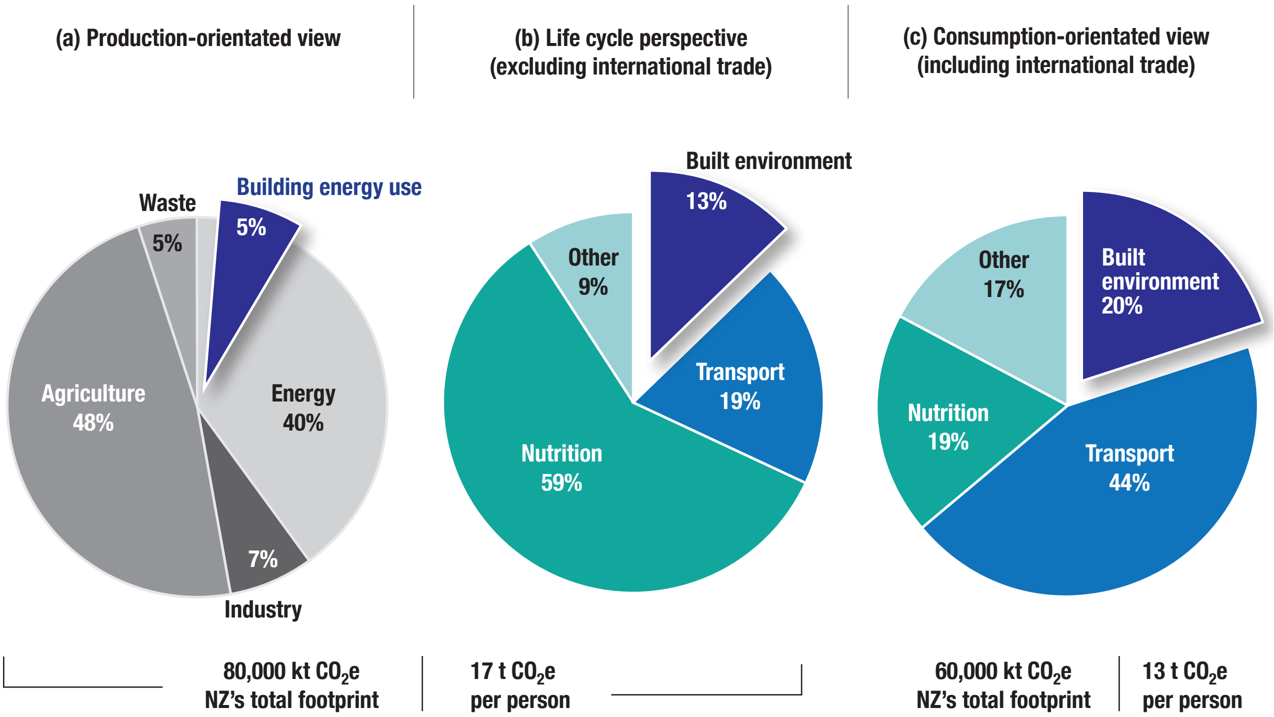


Figure 2: Breakdown on New Zealand's Carbon emissions in 2015 from a) a production perspective, b) a lifecycle perspective, and c) a life cycle consumption perspective (thinkstep-anz, 2018).

However the 2018 thinkstep-anz report "The carbon footprint of New Zealand's built environment – hotspot or not?" shows that:

- When considered from a consumption rather than production perspective, contributions from buildings are much more significant. Emissions from agriculture tend to dominate when seen from a production perspective, but over 90% of the goods consumed from these activities are exported, so New Zealand consumers can't influence them.
- Emissions 'embodied' in the construction of buildings (primarily due to the production of construction products), are similar in scale to the emissions from the operation of buildings over their lifetime. Other studies around the world have shown that typically operational emissions are a factor of 2 to 5 times larger than the embodied emissions of buildings, so this finding for New Zealand is unusual and the report offers a number of explanations for this result.

Emissions from the construction and operation of buildings in New Zealand need to be reduced if we are to meet our obligations under international agreements. New Zealand building owners and operators can influence these emissions, in contrast to emissions from agricultural products that are ultimately consumed outside the country.

The New Zealand Government enacted the Zero Carbon Bill in November 2019, committing the country to reducing net emissions of all greenhouse gases to zero by 2050 (with some exemptions for biogenic methane). To achieve this, multiple solutions will be required across all sectors of society. The New Zealand construction industry has a significant part to play in reducing emissions from buildings in New Zealand. This guide sets out to show how wood in construction can be used to accomplish this.

3. WOOD, CARBON AND BUILDINGS

3.1 WOOD AND SUSTAINABILITY

Of the three elements that make up the triple bottom line of sustainable development, environmental sustainability is most frequently associated with wood. The renewable quality of wood, its ability to store Carbon and low Carbon footprint are at the forefront of its environmental sustainability profile. However arguments can be made for its social and economic sustainability also, for example:

- Wood can be a low-cost option for a building's construction, when compared to other structural materials like steel or concrete. Provided it is used in the most suitable form for the application, and is appropriately durable, wood can be an economically sustainable choice of construction material.
- Health and wellness benefits for the occupiers of timber buildings are well documented. As a natural material, when timber is exposed in the internal finishes of a building, evidence suggests it can provide the same human health benefits as our response to other views of nature, such as natural light, plants and water, including positive psychological effects and lowering stress reactivity of the autonomic nervous system.

Whilst we have seen that the use of wood in construction can contribute to all 17 SDGs through a sustainable wood value chain, and can influence a number of sustainability impact categories, this guide will focus on one of the environmental sustainability credentials of wood: namely the role it can play in mitigating greenhouse gas emissions (see Figure 3).

This is a direct contribution to SDG 13 (Climate Action) and the Paris Agreement on Climate Change.

Other New Zealand Wood Design Guides (e.g. Chapter 2.2: Social and Health Benefits if Timber Construction) can be consulted for more detail on other sustainability aspects of timber.

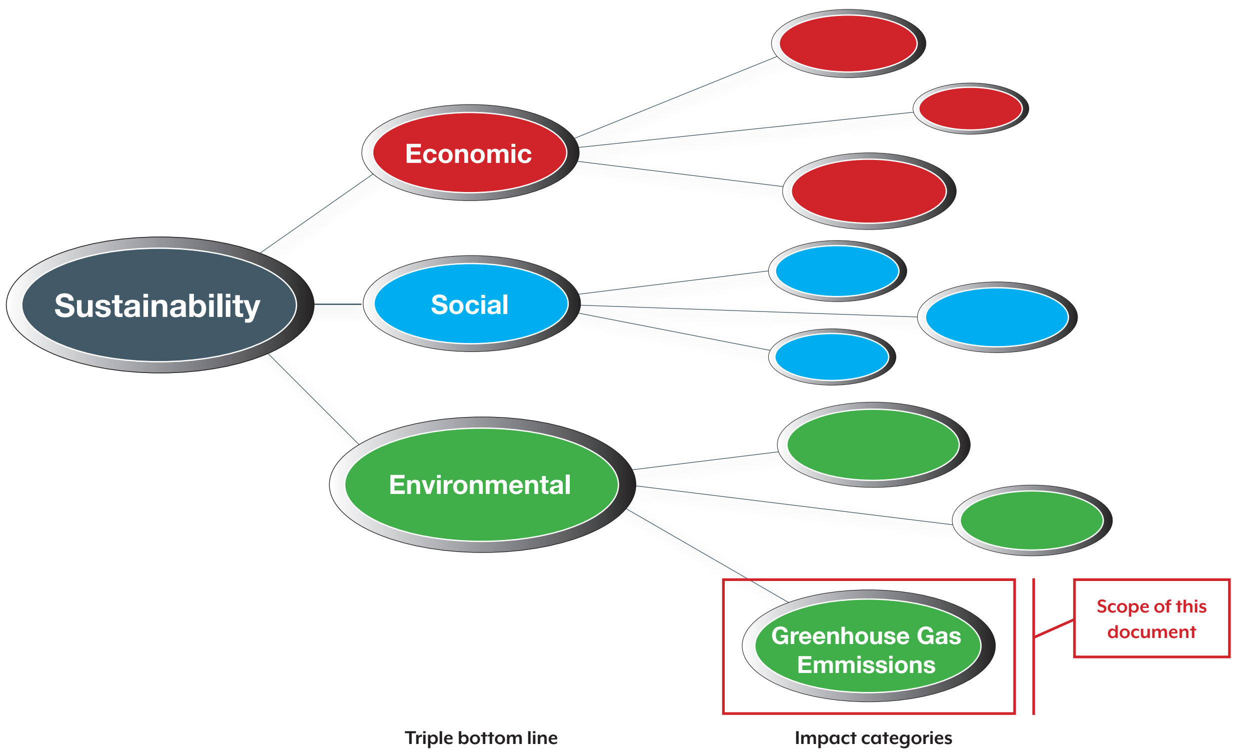


Figure 3: Sustainability impact categories.

3.2 WOOD AND CARBON

The direct Carbon benefits of using wood in construction are twofold:

- The Substitution Effect: Wood has a lower Carbon footprint than steel or concrete, therefore reduces the Carbon emissions of buildings when used in the place of more traditional but energy intensive materials such as steel and concrete.
- Carbon Storage: The use of wood in long-life entities such as buildings locks away Carbon previously sequestered by trees from the atmosphere for the long-term, instead of a potential shorter term re-emission in the atmosphere at the tree or another product's end-of-life. When wood is sourced within a sustainable forestry supply chain, the storage of Carbon can contribute to optimising the Carbon sequestered from the atmosphere by re-growing forests.

The metric for assessing the climate change impacts of greenhouse gas emissions is Global Warming Potential (GWP). This is expressed in units of CO_2 equivalent (CO_2-eq) over 100 years, commonly referred to as 'Carbon emissions', or even simply 'Carbon'.

3.3 COMPARING CARBON IN NEW ZEALAND BUILDINGS

3.3.1 Comparison of Structural Materials and Products

The most frequently compared structural materials are steel, concrete and timber. (Timber is the word used to describe wood at any stage after the tree from which it came has been felled.) The Carbon emissions associated with the production of 1kg these materials are presented in Figure 4:

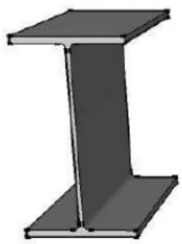
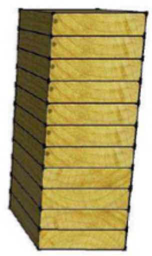
			
Construction Material	**Structural steel**	**30MPa in situ concrete including reinforcing steel**	**Wood, glulam timber**
Embodied Carbon: kg CO_2-eq /kg (with no stored Carbon)	**2.85**	**0.21**	**0.61**
Embodied Carbon: kg CO_2-eq /kg (including stored Carbon)	**2.85**	**0.21**	**-1**

Figure 4: Embodied Carbon (cradle-to-gate) of steel, concrete and timber by unit weight, data from BRANZ CO_2nstruct.

Whilst it is important to know these values, and the methodologies behind their calculation (which is explained in following sections), values on a per kg basis are not particularly useful when comparing different options for use in building design, owing to the different strength-to-weight ratios of each material.

To account for this, the Carbon emissions associated with the production of 1 metre of beams of (approximately) equivalent structural performance made from each of these materials is presented in Figure 5:

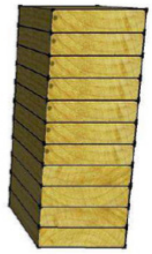
			
Construction Product	**Structural steel (152x89x16UB)**	**30MPa in situ concrete including reinforcing steel (200mmx150mm)**	**Wood, glulam timber (360mmx90mm)**
Embodied Carbon: kg CO_2-eq /metre (with no stored Carbon)	**45**	**15**	**10**
Embodied Carbon: kg CO_2-eq /metre (including stored Carbon)	**45**	**15**	**-16**

Figure 5: Embodied Carbon (cradle-to-gate) of equivalent steel, concrete and timber beams, based on a typical upper floor beam of 6m span, using data from BRANZ CO_2nstruct.

3.3.2 Comparison of Buildings

The most useful comparisons are made between equivalent whole buildings of different structural frames. These will account for the different loads the structure must resist, even for the same functional requirements, due to the different self-weights of the structures. Crucially, these comparisons should include the size of the foundations, which account for a significant proportion of the embodied Carbon. Figures 6, 7 and 8 show examples of these.

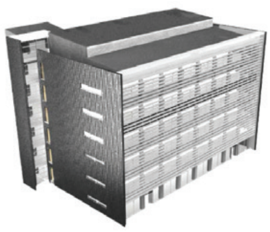
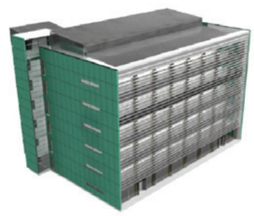
			
Structural frame	**Steel eccentrically braced frame**	**Precast concrete frame and shear walls**	**Prefabricated Laminated Veneer Lumber (LVL)**
Embodied Carbon: tonnes CO_2-eq (including stored Carbon)	**1615**	**1576**	**125**
Ratio	**12.9**	**12.6**	**1**

Figure 6: Embodied Carbon (cradle-to-gate) of alternative structural designs for a 6 storey, 4200m² building (John et al, 2009).

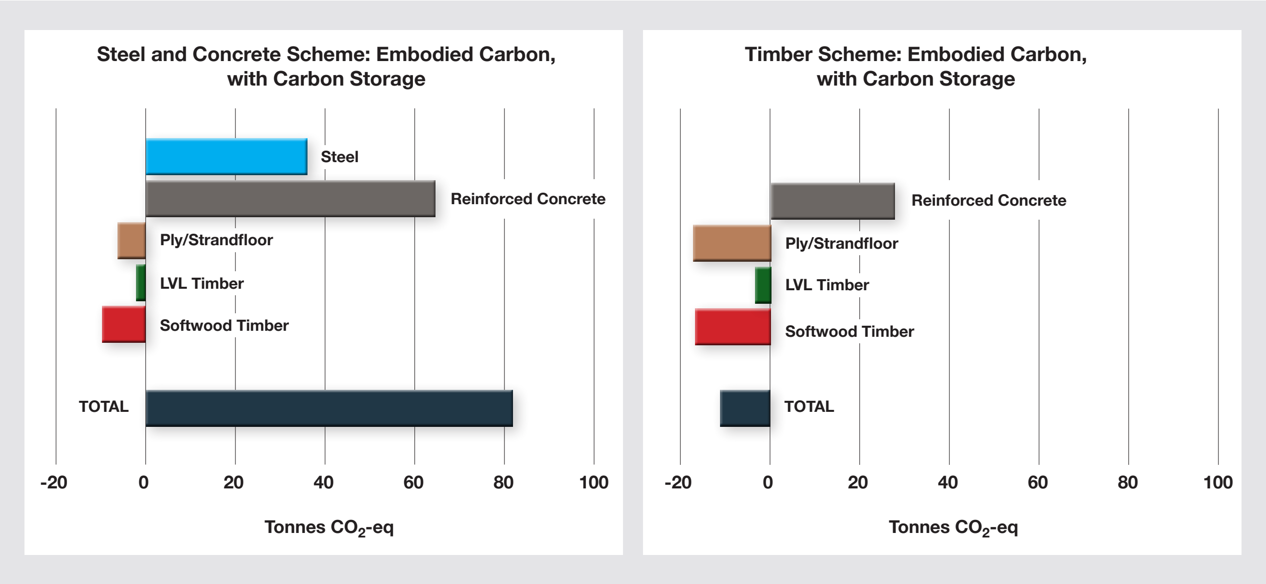


Figure 7: Embodied Carbon (cradle-to-gate) of two concept designs for a 2 storey, ~450m² building.

Two alternative structural schemes for the same building are evaluated in Figure 7, based on concept design information. The first consists of a steel frame and suspended concrete floors, with some timber elements in the roof and walls. The second scheme consists of a lightweight traditional timber structural frame and floors. The embodied Carbon of each structural element is evaluated by multiplying the embodied Carbon coefficient for the material by the material quantity; these are summed to give the total embodied Carbon for the building. Note that the timber elements contribute a negative embodied Carbon (as Carbon storage has been included), offsetting the positive values from the other elements.

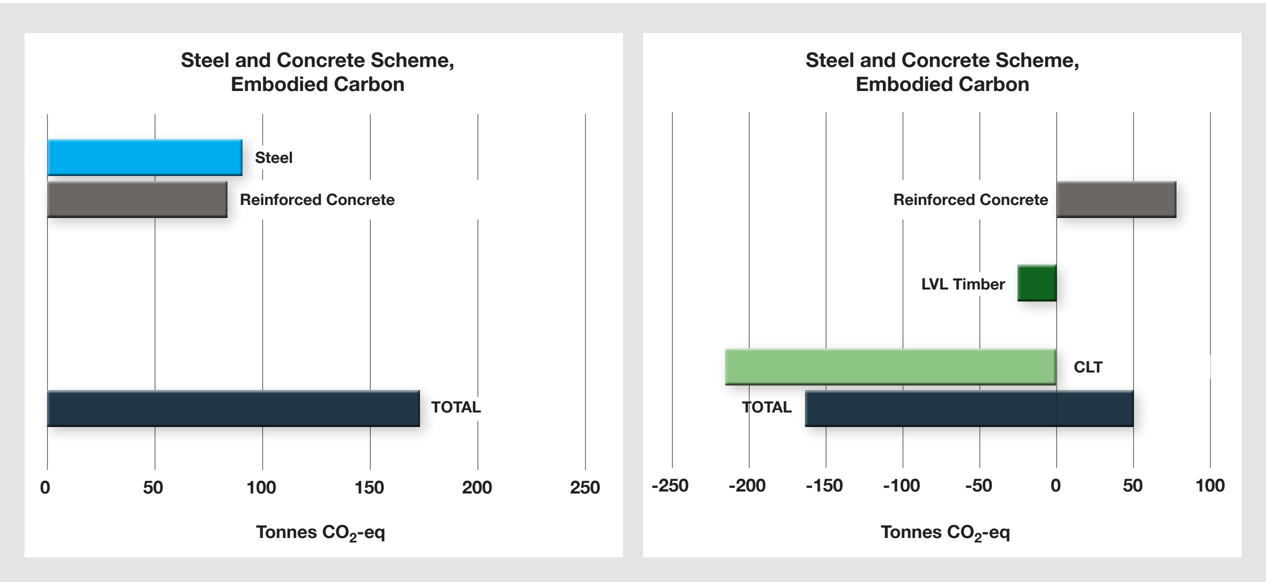


Figure 8: Embodied Carbon (cradle-to-gate) of two concept designs for a 3 storey, ~1400m² building.

Figure 8 is the evaluation of two alternative structural schemes for a much larger building: the first is another steel frame and concrete floor concept, but here the second scheme is a mass timber structure, consisting of Cross Laminated Timber (CLT) panels for floors and walls, and Laminated Veneer Lumber (LVL) beams. The embodied Carbon was evaluated in exactly the same was as for Figure 7. The heavier steel and concrete structure required deeper foundations, which increased the impact for this scheme.

3.3.3 Carbon Storage in Timber Buildings

Note that the results of the comparison studies in the previous section were all based on 'cradle-to-gate' values, and it was specified whether 'stored Carbon' was included in the values for the timber elements. This is due to the complexities of crediting the Carbon stored in the timber (as a result of sequestration by trees) in studies that are not over the whole life cycle of the building. These issues are discussed in Section 5.1.1 of this guide, but it is useful to quantify the amount of Carbon that is stored in a building

Detailed calculations are included in Appendix A, but for an overview, consider surfaced, kiln dried Radiata pine, the most common wood used for timber construction used in New Zealand. At 11.6% moisture content, and density of 486kg/m^3, 1m^3 of this timber stores 798kg of CO_2, in the form of biogenic Carbon.

A typical 200 m^2 timber framed house in New Zealand contains 30m^3 of surfaced, Radiata pine kiln dried timber framing. This will therefore store around 24 tonnes of CO_2-eq.

4. QUANTIFYING CARBON EMISSIONS IN CONSTRUCTION

The following sections explore the issues around ensuring robust and reliable figures are used when comparing the Carbon footprint of wood products used in construction.

4.1 LIFE CYCLE ASSESSMENT

To assess the sustainability of a product, process or system, the environmental, social and economic impacts must be considered not just in the present day, but also in the future (when they will directly affect the 'future generations' referred to in the Bruntland definition). For environmental impacts, this is done by carrying out a Life Cycle Assessment (LCA), also known as Life Cycle Analysis.

An LCA quantifies the environmental impacts over the whole life cycle of a product or service, accounting for the polluting or other environmental damaging effects of all the processes that occur.

A full LCA considered many categories of environmental impacts: the amount of Carbon Dioxide (CO_2) and other greenhouse gas emissions are reported under the category referred to as Global Warming Potential (GWP). Other impact categories include energy use, water depletion, eutrophication and toxicity.

An LCA reports values for each impact category at each life cycle stage of the product or service, within the limits of a carefully defined 'system boundary' or 'product system'.

In order to make comparisons between different products, LCAs define a 'functional unit' for which the results apply. For wood products used in construction, this is typically a unit volume of the product, for example $1m^3$ of sawn, kiln dried softwood. For some other construction products such as structural steel, a unit weight, such as 1kg or 1 tonne is used. As demonstrated in section 3.3.1 however, although these numbers are important, comparing the impacts of the unit mass or volume of different construction products rarely allows meaningful conclusions to be drawn on their relative environmental impact when used in a building.

The concept of a 'circular economy' is often used in the same conversations as LCA, but their meanings are slightly different. A Life Cycle Assessment is simply an assessment of environmental impacts over the lifecycle of the product under consideration, whereas a Circular Economy is a system where the lifecycle of materials is maximised, usage optimised and at the end of life all materials are reutilised.

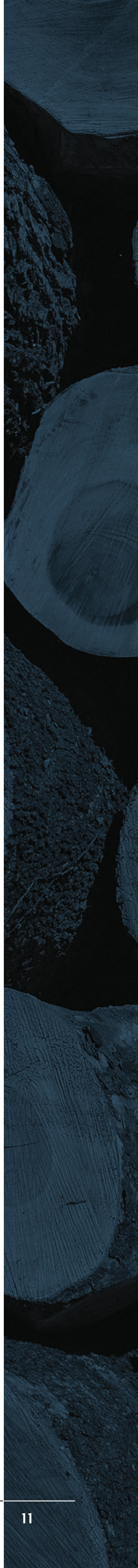
For more detailed information on Life Cycle Assessment, refer to Appendix B.

4.2 ENVIRONMENTAL PRODUCT DECLARATIONS

An Environmental Product Declaration, or EPD, is a concise, readable, third party verified document, based on international standards, that includes the reporting of LCA-based results, in addition to other environmental information. As such it can be considered as a reliable document for information on environmental impacts of products (including Global Warming Potential), which can then be used to support the comparison of alternative products, including construction products or materials.

An EPD may be produced for a specific material or product (a product-specific EPD), or an average of the same or similar materials or products within a sector (average product or collective EPD). They must be developed in accordance with input from interested stakeholders and comply with the international standard on EPDs, which for construction products are typically:

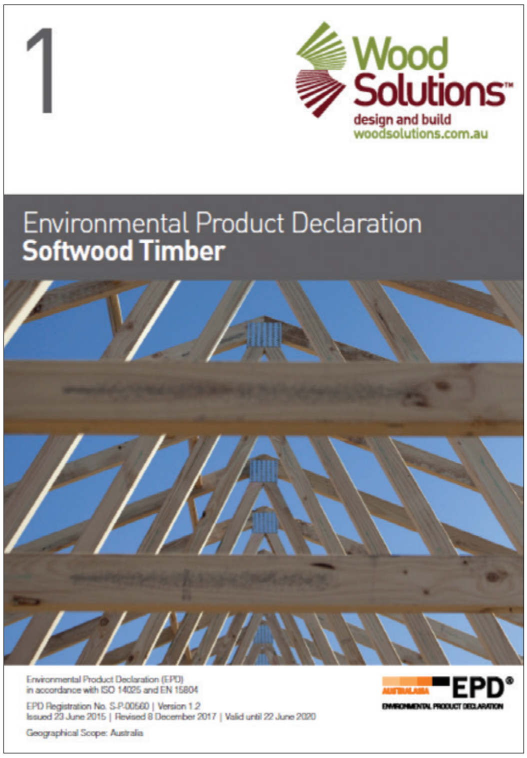
- ISO 14025: Environmental labels and declarations, which refers to EPDs as Type III environmental declarations, and
- EN 15804: Sustainability of Construction works. Environmental Product Declarations, core rules for the product category of construction products.



This ensures there is consistency and comparability when calculating potential impacts of materials or products within a product category.

Often a great deal of data, some commercially sensitive, is required for an EPD, which manufacturers may be reluctant to make public for commercial reasons. An EPD is a way to offer insight into the environmental impacts of a product or service but protect commercial information.

Once the LCA work behind an EPD has been carried out, and the results verified by an independent third party, the EPD document is published and registered with an EPD scheme and is then freely available for anyone to view.



The EPD for Australian softwood timber produced for Wood Solutions in 2017.

EPDs are the primary tools for comparing the environmental impact of construction materials. They are used to provide robust and product specific data that can be aggregated to calculate the environmental impacts of a whole building, often in preference to generic data from LCA databases such as Gabi or SimaPro. They are also used increasingly as eco labels for products by their manufacturers in their own right. The robust methodology behind them, and the fact they are carried out in accordance with international standards and are independently 3rd party verified, means manufacturers use them as a way to differentiate their products from competitors, as customers become more aware of the environmental impacts of construction.

In the context of a whole building LCA, the EPD for a construction materials or product can only report the impacts from the production and end-of-life stages and any loads/benefits beyond the system boundary. Impacts from the other stages (transport, maintenance) are a function of how the material is used in a particular building. However they can be estimated when the site location and source of material is known (to evaluate the transport impacts) and the design lives of both the product and the building are known (to evaluate the maintenance/replacement impacts).

4.3 EPDS FOR NEW ZEALAND CONSTRUCTION PRODUCTS

Construction products made in New Zealand can have EPDs registered with EPD Australasia, which was established in September 2014 as a cross-Tasman EPD programme. The programme is affiliated with The International EPD® System, one of the largest and oldest EPD scheme providers globally. This system registers EPDs that have been calculated based on the EN 15804 standard, so there is confidence that the same rules and methodologies have been applied to all products.

EPD Australasia is a not-for-profit joint venture between the Life Cycle Association of New Zealand (LCANZ) and the Australian Life Cycle Assessment Society (ALCAS). Its launch in New Zealand has been supported by the BRANZ Building Research Levy.

Each EPD is reviewed every five years to ensure that the reported environmental indicators in the EPD remain valid and representative of the product being supplied.

The first EN 15804 compliant EPD developed in New Zealand for a construction product was by Allied Concrete, who published an EPD in 2014 for ready-mixed concrete made at 28 batching plants around New Zealand. The number of EPDs is growing: as of January 2020, there are over 7300 verified EPD to EN15804 for construction products registered globally. Of those, 55 are registered under the EPD Australasia programme.

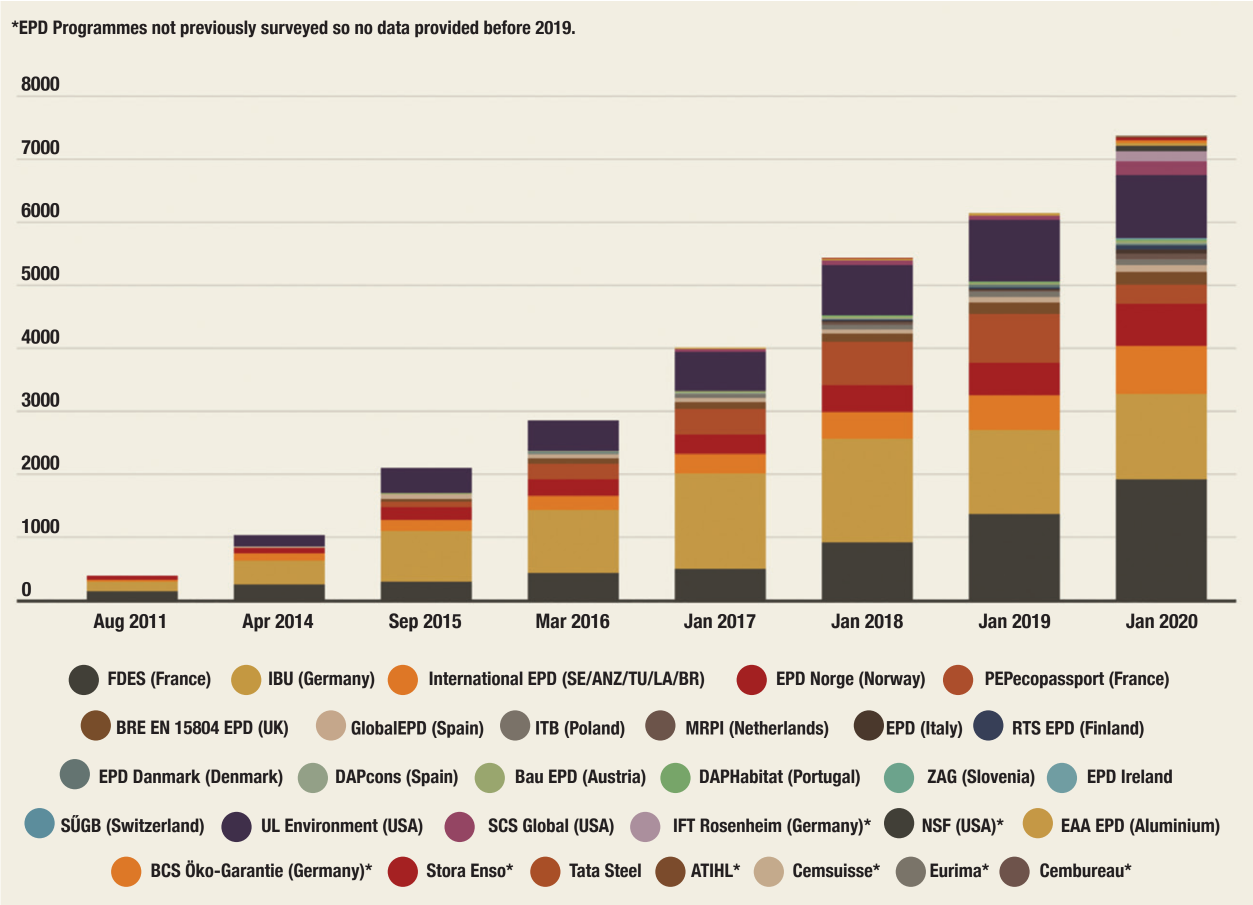


Figure 9: Growth of Construction product EPDs to EN15804 (ConstructionLCA, http://bit.ly/2020EPD).

In 2019 the Wood Products and Manufacturing Association (WPMA) released an EPD for timber products made in New Zealand from Radiata pine, covering sawn and surfaced kiln dried timber, finger jointed timber, Glulam and CLT. Rather than data being provided by a single manufacture for each product, it is a collective EPD, with data for all the products being provided by 10 manufacturers in New Zealand, and representative values for each product given. Together with the Scion 2010 report on the Carbon footprint of LVL timber, this means that there is now a reliable, country-specific dataset for the embodied Carbon of all the mainstream timber products used in construction in New Zealand.

4.4 LIFE CYCLE STAGE REPORTING

A key aspect of LCAs and EPDs is the categorisation of life cycle stages of the product system, which for applications in the construction industry is a building, or a construction material or product.

The different life cycle stages of a building, or the construction products which make up the building, are separated into discrete entities as shown in Figure 10:

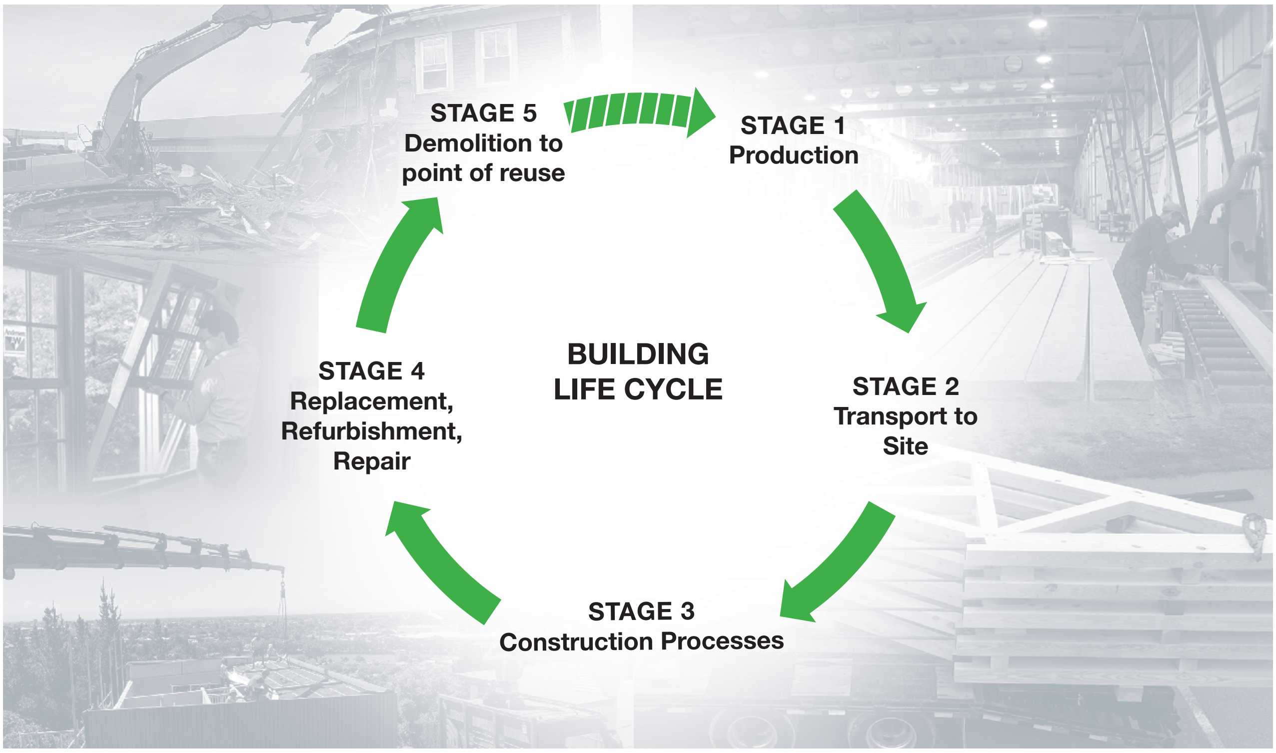


Figure 10: Life cycle stages for construction products and buildings.

Typically the production stage will dominate the environmental impacts of a construction product. This is the only stage included in so-called 'cradle-to-gate' values, as it covers the environmental impacts of the processes involved in extracting all the raw materials from their natural state (the 'cradle'), transporting to manufacturing facilities, and the processes involved in producing the product to the point at which it can be delivered to the end customer (the factory 'gate').

This is in contrast to 'cradle-to-grave' values, which in addition to the cradle-to-gate impacts, takes into account the additional environmental impacts of all the other life cycle stages, namely:

- transportation to the site where it will be used,
- any construction processes involved in creating the building on site,
- any repair or refurbishment processes that the product will undergo during the building's life,
- and finally demolition and any waste or recycling processes, up to the end of life state, the 'grave', or the point of reuse if material can be reused.

Within the LCA standard for construction products, EN 15805, these life cycle stages are defined as 'Modules' according to Figure 11, and the environmental impacts are reported for each module in an EPD. Some life cycle stages have much great environmental impacts than others, and so it is normal for some Modules to be omitted if they are deemed to be insignificant.

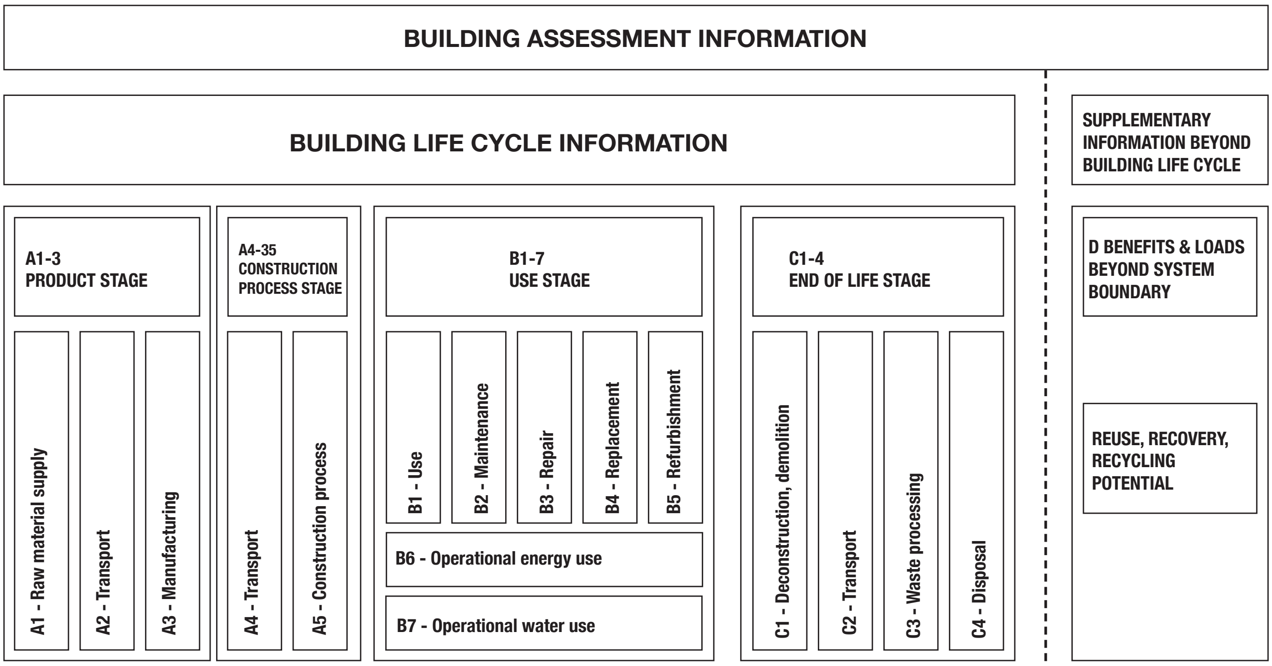


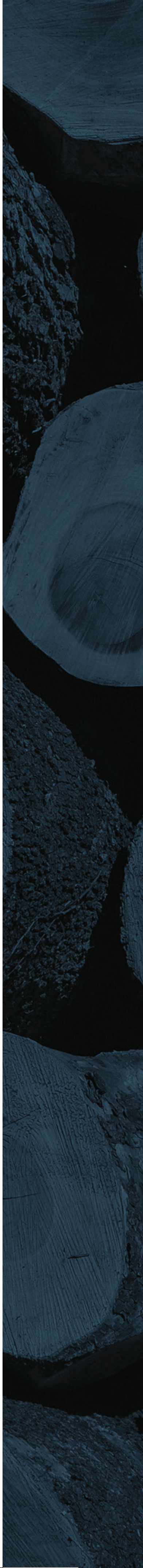
Figure 11: Life cycle stage modules for construction products used EPDs in accordance with EN 15804.

The standard EN 15978 defines the methods by which an LCA for a building (as opposed to a construction product) is carried out, including rules for defining the system boundary for the LCA and what processes needs to be included in each module. It also defines the scenarios that are to be assumed for stages that occur in the future, which is very important for the end-of-life stages in Module C.

Modules A1-A3 are typically reported together as one value, as they constitute the 'cradle-to-gate' life cycle stage. For a building, the value reported here is the aggregate of the Module A1-A3 values for all the constituent materials and products that go into the building during construction.

An EPD for a construction material or product that is produced in accordance with the EN 15804 standard must report environmental impacts within this Module framework. The bulk of the impacts from activities and processes that go on during a building's construction and operation (Modules A4-A5 and B) are independent of the materials and products which together make up the building's fabric. The main impacts from the construction materials and products that form the building fabric is within the cradle-to-gate life cycle stage, therefore, EPDs for construction products must report values in Modules A1-A3.

Many construction product EPDs will report values for Modules C3, C4 and D. These cover the waste processing and disposal processes in the end-of-life stage, and benefits and loads beyond the system boundary. As the construction industry is becoming increasingly aware of whole life impacts, product manufacturers will need to consider the potential end-of-life scenarios for their products, including possibilities such as disposal to landfill, recycling or reuse. EPDs can report different values in these stages for each scenario considered.



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			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits & 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	C4	C3	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	X	X

X – included in the EPD
MND – Module not declared (such a declaration shall not be as an indicator result of zero)

Figure 12: Example of Reporting of Life Cycle Stage Modules in an EPD in accordance with EN 15804.

Module D is included to recognise the benefits of a product that can easily be recycled. The reduced environmental impacts will not be realised within the building for which the LCA is being carried out, but within the next building or product system where the recycled product will be used. Since LCA methodologies have tight definitions for the 'system boundary', Module D offers a way of reporting the benefits that an easily recyclable material will bring to the next system. The LCA standards have methods which avoid the double counting of these benefits.

EN 15804 was revised in June 2019 with one of the main updates being that EPDs for all construction products and materials now need to declare values in Modules C1-C4 and D as well as modules A1-A3.

4.5 CARBON FOOTPRINT

A Carbon footprint is the result of a life cycle assessment using the single impact category of climate change.

The terms "Carbon" and "CO_2" are often used interchangeably. Carbon is a chemical element and Carbon Dioxide (CO_2) is a gas with a molecular structure of one Carbon atom and two Oxygen atoms. However, in the context of the impact of emissions of Carbon Dioxide and other gases that contribute to the greenhouse effect in the earth's atmosphere, often "Carbon" is used as shorthand: this is the case for the term "Carbon Footprint".

A Carbon footprint is defined as the sum of greenhouse gas emissions and removals in a product system, expressed as a "CO_2 equivalent", which can be shortened to CO_2-eq, CO_2-e, ECO_2 etc. The CO_2-eq of a specific amount of a greenhouse gas is calculated as the mass of a given greenhouse gas multiplied by its global warming potential. ISO 14067:2018 defines a CO_2 equivalent unit as a "unit for comparing the radiative forcing of a greenhouse gas to that of Carbon Dioxide."

Two important properties of greenhouse gases are particularly relevant when considering their environmental impact: the amount of warming that they cause, and the length of time they remain in the atmosphere before being broken down. The CO_2-eq unit allows the impact of different greenhouse gases to be measured by the amount of Carbon Dioxide that would create the same amount of global warming. In this way, emissions of all greenhouse gases from a particular product or process across a full life cycle can then be summed up to give a single value, with the unit CO_2-eq, expressing its climate change impact, or Global Warming Potential (GWP) in a quantitative way.

The majority of the GWP of timber construction products is due to Carbon Dioxide emissions from energy use during manufacture, transport, and potentially combustion or decomposition at end of life. Other greenhouse gases that many contribute to the Carbon footprint of timber products include methane, which may be emitted when timber decomposes at its end-of-life phase. This is covered in detail in Section 5.3.5.

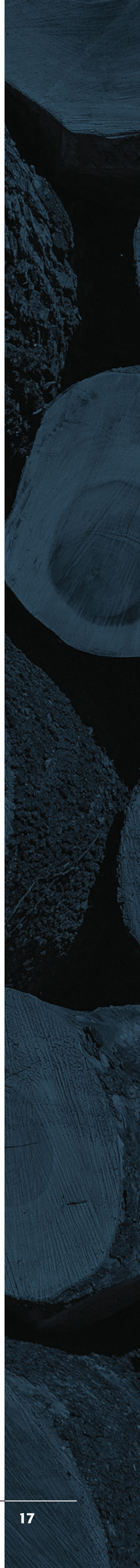
A Carbon footprint can be, and has been, carried out on a wide range of products and services, with the results published in a wide range of formats, ranging from academic papers to popular science books (for example “How bad are bananas?: The Carbon Footprint of Everything” by Mike Berners-Lee).

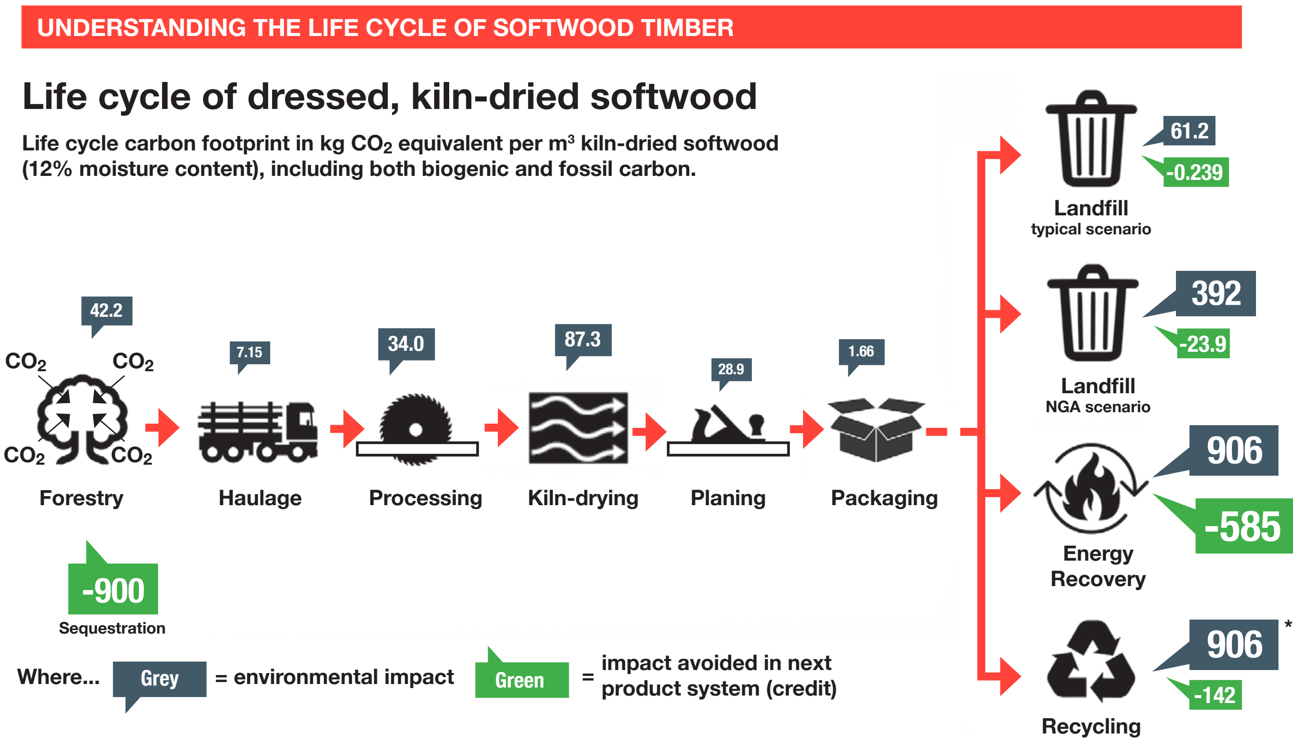
In construction, a Carbon footprint can be calculated for materials, construction products, or buildings in their entirety. As shown in Section 3.3.1, the Carbon footprints of timber structural elements can be compared to those of structural elements made from other materials for all or some limited number of life cycle stages.

4.5.1 Carbon Footprint of Construction Products

Being based on a product LCA, an EPD discloses that product’s Carbon footprint, expressed in kgCO_2-eq within the Global Warming Potential (GWP) impact category. Moreover, within an EPD the GWP value is clearly reported for each life cycle stage, which is not always specifically defined in other Carbon footprint reporting documents (for example product datasheets, brochures, or even technical reports).

For an EPD developed in accordance with EN 15804, the value for Modules A1-A3 will be the Carbon footprint of the construction product for the ‘cradle-to-gate’ life cycle stage. This is the most commonly used type of Carbon footprint, often referred to as simply the ‘embodied Carbon’. It should be noted that it will not include the greenhouse gas emissions from other life cycle stages of the product, such as demolition and waste processing, which are generally included in a ‘whole life’ embodied Carbon assessment.





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

	Production	Landfill (typical)	Landfill (NGA)	Energy Recovery	Recycling
Parameter [Unit]	A1-A3	C4	C4	C3	C3
GWP [kg CO_2-eq.]	-699	61.2	392	906	906
GWPF [kg CO_2-eq.]	183	57.8	58.0	5.59	5.59
GWPB [kg CO_2-eq.]	-882	3.34	334	900	900
ODP [kg CFC11-eq.]	4.72E-11	2.79E-11	2.79E-11	2.41E-13	2.41E-13
AP [kg PO_2^{3-}-eq.]	1.10	0.181	0.203	0.0352	0.0352
EP [kg CO_2-eq.]	0.275	0.0233	0.0287	0.00823	0.00823
POCP [kg C_2H_4-eq.]	0.680	0.0115	0.0760	0.00305	0.00305
ADPE [kg Sb-eq.]	7.86E-05	1.16E-05	1.16E-05	6.97E-08	6.97E-08
ADPF [MJ]	2,250	838	838	72.9	72.9

Figure 13: Extracts from Wood Solutions EPD560 for Australian softwood timber, embodied Carbon values highlighted.

Figure 13 show the processes considered in the assessment of environmental impacts of the cradle-to-gate (Modules A1-A3) and end-of-life (Module C3 or C4 where appropriate) for 1m^3 of dressed, kiln dried softwood, and how the results are reported. The Carbon footprint is the top row of the table, Global Warming Potential (GWP), expressed in kg CO_2-eq.

4.5.2 Carbon Footprint of Buildings

A Carbon footprint of a single construction product or material is relatively simple to evaluate, within clearly defined system boundaries (such as cradle-to-gate), and the growing number of EPDs is making this data more widely available.

The Carbon footprint data is required for many construction products to determine the overall Carbon footprint of a building. This information is typically used by a building design team to try to compare the Carbon footprints of different design options, for example a timber frame against a concrete frame for a building, as shown in Section 3.3.2.

To conduct a full Carbon footprint for a building involves multiple levels of complexity, on account of the number and variety of constituent products, and the uncertainty on emissions over the whole life cycle. 50 years is a typical design life for a building, so for a whole life cycle Carbon assessment, normally conducted over a 100 year period, assumptions must be made about emissions at the end-of-life stage, that may occur many years into the future.

In addition to this, the Carbon footprint of a building over its lifetime includes not only the total Carbon footprints of its constituent products, known as 'Embodied Carbon', but also the 'Operational Carbon. (Like the term 'Carbon Footprint', the word 'Carbon' in the terms 'Embodied Carbon' and 'Operational Carbon' is shorthand for Carbon Dioxide, and includes emissions of all greenhouse gases, not just CO_2, expressed in kg CO_2-eq.)

A building's Operational Carbon refers to greenhouse gases emitted due to the energy consumption of the building while in use (or 'in operation'), primarily due to heating, cooling, lighting and other operational processes. These are relatively simple to calculate at the design stage of a new building , however there are normally uncertainties and discrepancies between the designed performance and the actual energy efficiency due to, for example construction quality issues and the building end users' operations and management behaviours).

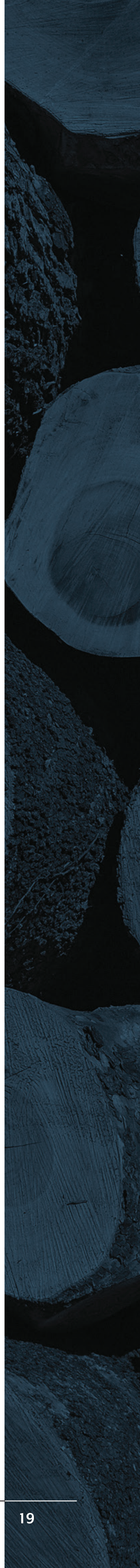
A building's Embodied Carbon is the aggregated carbon footprints of all the materials and products that form the building fabric, over the building's lifetime (i.e. it includes the replacement of products that may occur under scheduled maintenance cycles).

It is important to consider that a full assessment of the Embodied Carbon of a building should not end at the construction stage. It extends through and beyond the operational stage, and includes end-of-life emissions of the constituent materials and products in the building. Thus the 'cradle-to-grave', not just the 'cradle-to-gate' Carbon footprint figures are required for each constituent part of the building fabric for a comprehensive Carbon footprint of a building.

Therefore to determine the Carbon footprint of a building, the Embodied Carbon of all constituent materials and products need to be evaluated over all the life cycle stages, and added to the Operational Carbon.

There is considerably more complexity in evaluating the Embodied Carbon of a building than the Operational Carbon. Whilst the latter can be relatively easily determined from the projected operational energy consumption (and appropriate fuel mix) used over the design life, the former requires a great deal more data, of constituent materials, transportation modes and distances, maintenance requirements and predictions of end-of-life scenarios.

Operational and Embodied Carbon can be mapped to the life cycle stage Modules as defined in the EN 15978 and EN 15805 standards as shown in Figure 14: the boxes highlighted blue are Embodied Carbon, only 4 (B1,B2, B6 and B7) are Operational Carbon impacts.



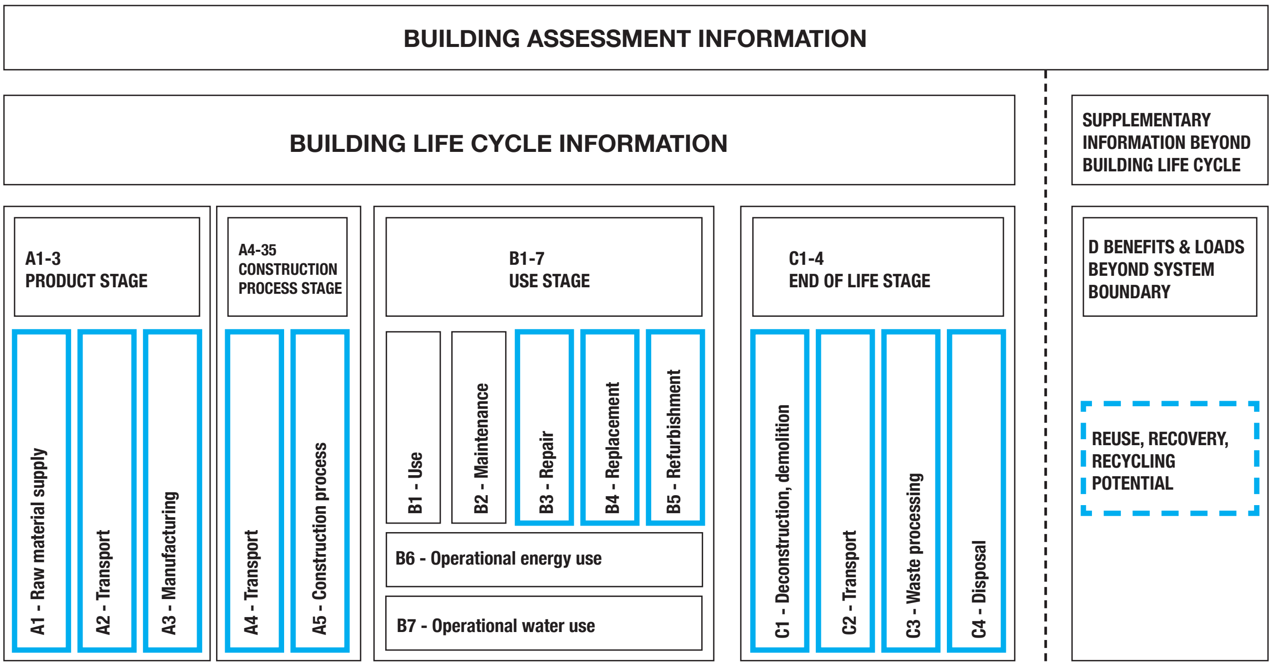


Figure 14: Life cycle stage Modules, with those including Embodied Carbon (not Operational Carbon), highlighted in blue.

It is useful to remember that in general the embodied Carbon of a building will be dominated by a few components, typically the foundations, ground and upper floor structure, and structural frame or walls. Effort should be focussed on getting good quality data for the high mass elements, or those that use significant quantities of high embodied Carbon materials, such as steel and concrete.

This difference in complexity is reflected in how Embodied and Operational Carbon of buildings is currently mitigated in building legislation. Most jurisdictions have regulatory instruments, as part of the national building code or elsewhere to limit Operational Carbon, through enforcing minimum energy efficiency standards. But due to a shortfall in industry expertise in assessing embodied Carbon, it is something that only a few countries have implemented mandatory controls to reduce, see Section 7.3.

Despite the complexities associated with assessing Embodied Carbon, it must be considered together with the Operational Carbon for a true whole Life Cycle Assessment of a building. Embodied Carbon is being increasingly recognised as contributing a significant proportion of a building's Carbon footprint, especially when Operational Carbon has already been reduced by energy efficiency legislation, as illustrated in Figure 15.

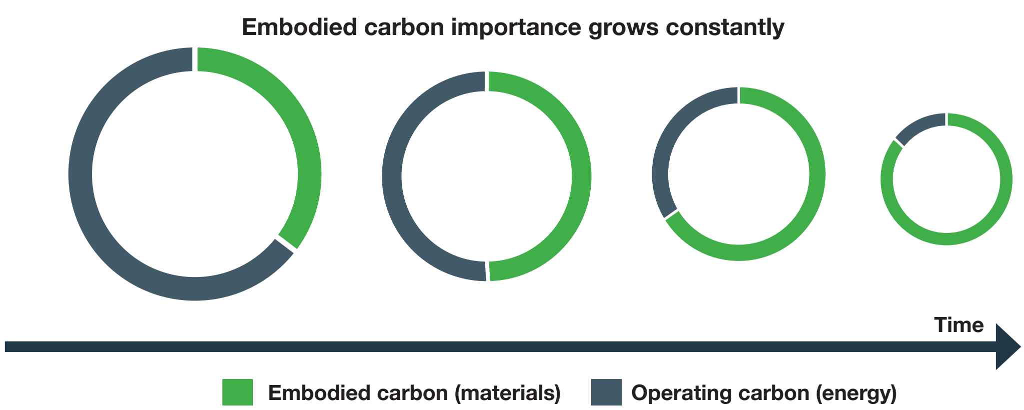


Figure 15: The importance of Embodied Carbon grows as Operational energy decarbonizes over time (The Embodied Carbon Review, 2018, Bionova Ltd).

Figure 16 shows that for 3 different types of building, the Embodied Carbon up to practical completion (i.e. Modules A1-A5) contributes between 35-51% of the Carbon Footprint, but this increases to 67-76% when considering the Embodied Carbon over all life cycle stages, Modules A1-D.

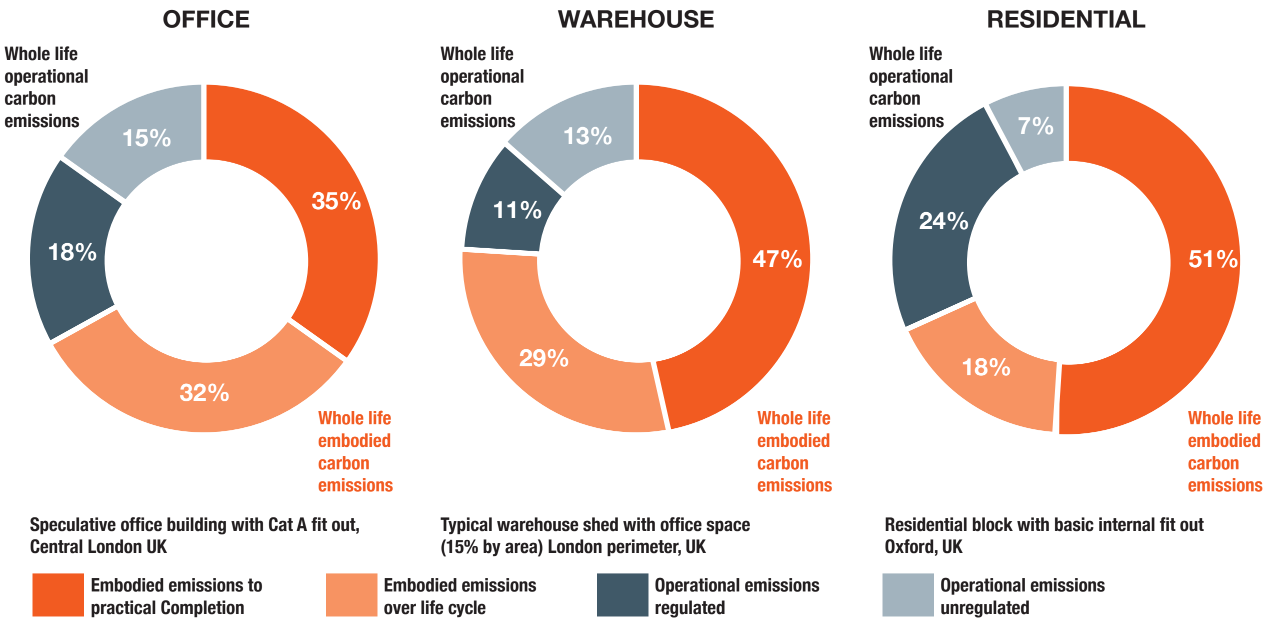
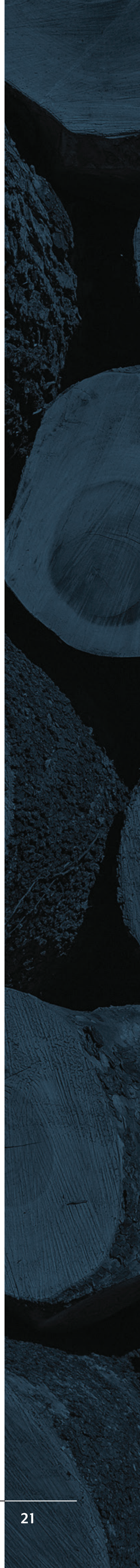


Figure 16: Relationships between Operational and Embodied Carbon for 3 building types (Sturgis, RIBA whole life Carbon guidance, 2017).

There may be trade-offs between Embodied and Operational Carbon (for example greater thermal efficiency of the building envelope to reduce Operational Carbon may result in an increase in Embodied Carbon) but there are no hard and fast rules for this.

The Embodied Carbon of New Zealand timber construction products at each life cycle stage is discussed in detail in the following sections.



5. EMBODIED CARBON OF TIMBER CONSTRUCTION PRODUCTS

In this section, the issues surrounding the embodied Carbon of timber products are discussed at each life cycle stage, using the data from the WPMA EPD published in 2019 to demonstrate how the methodology that has been adopted is manifested quantitatively in the values for Global Warming Potential (GWP). The EPD is carried out in accordance with the EN 15804 standard, and as such, breaks down the lifecycle of timber products into the Modules as already seen in Section 4.

Product stage			Construction 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	Construction / Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to waste processing	Waste processing	Disposal	Reuse Recovery Recycling
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

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

Figure 17: Life cycle Modules reported in the WPMA EPD for New Zealand timber products.

5.1 MODULES A1-A3: PRODUCTION

For timber construction products, the GWP impact at this life cycle stage is the combination of the process of Carbon sequestration in the forest while trees are growing, and the Carbon emissions during wood harvesting and timber product manufacturing.

5.1.1 Module A1: Carbon sequestration by trees

Trees that are felled to produce timber remove Carbon Dioxide (CO_2) from the atmosphere during their growth. It is during this stage that timber construction products gain a significant advantage in embodied Carbon over other construction materials.

In general terms, Carbon sequestration is the process of removing CO_2 from the atmosphere, and thus reducing the concentration of greenhouses gases there, which provides the benefit of mitigating the greenhouse effect and the consequential global warming. Many biological processes other than photosynthesis in plants and trees sequester CO_2 from the atmosphere and store it in other forms, including for example the uptake of Carbon in soils and the oceans.

Trees remove Carbon from the atmosphere by transforming it into biomass as they grown, including wood and leaves.

The Carbon stored in a standing tree's biomass, which is then harvested and transformed into wood products is known as 'biogenic Carbon'.

From a Module A1 life cycle stage perspective, when a new forest is established where there was previously no tree cover (a process known as afforestation), the GWP result is a net decrease in atmospheric CO_2 concentration, and a net increase in biogenic Carbon in the growing forest trees' biomass. Where a forest is managed in a sustainable way such that for every tree felled, a replacement tree is planted, and while the Carbon in the timber from the felled tree remains stored as biogenic Carbon in timber products, instead of being returned to the atmosphere at harvest or when the tree dies, the Module A1 GWP result is still a net decrease in atmospheric CO_2. Therefore, since the wood biomass resource extraction results in a net decrease in atmospheric CO_2, the GWP for Module A1 is a negative value, indicating a beneficial GWP impact. (Refer to Appendix A for detailed calculations of the amount of Carbon stored in New Zealand timber products.)

In contrast, almost all other resource extraction processes, such as mining, quarrying and chemical manufacturing processes, use energy and therefore release CO_2 into the atmosphere, resulting in a net increase in atmospheric CO_2.

These, and all other processes that result in CO_2 emissions, are detrimental impacts, and are expressed as positive values.

However, a fundamental condition required to justify the beneficial effects of Carbon sequestration in the context of timber construction products is the ongoing sustainable management of the forests from which the wood was sourced. Without this condition, the net reduction in atmospheric CO_2 as a result of the use of the timber cannot be justified. A discussion on the sustainability of New Zealand forests is included in Appendix C.

5.1.2 Modules A2-A3: Manufacturing processes

The wood product manufacturing processes as shown in Figure 18 typically cause Carbon emissions. However, they rarely exceed the beneficial effect of Carbon sequestration by trees that happens during this stage, so the net result for GWP for the product stage Module A1-A3 is almost always negative for wood products.

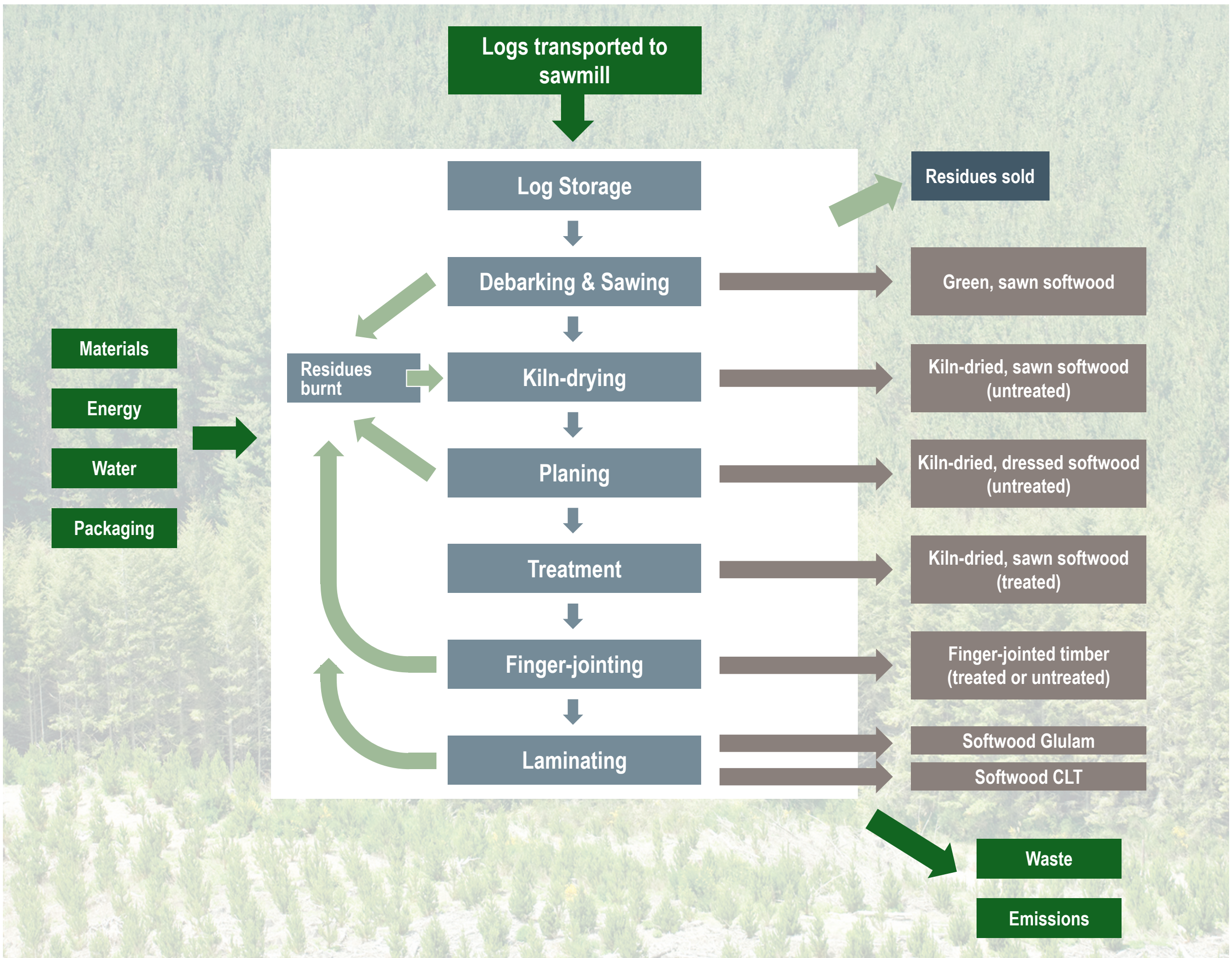


Figure 18: Manufacturing processes included in Module A1-A3 in the WPMA EPD for New Zealand timber products.

When timber is sawn from a log it may have a moisture content (oven dry basis) of between 40 to 200%. For most purposes, the timber must be dried to a moisture content of between 12 to 20%. To do this, the timber is usually stacked in kilns, with small timber fillets laid between the layers. Heated air is forced through the fillet spaces between the layers to evaporate moisture from the surface of the timber. The energy required for this process is responsible for the majority of the emissions at this life cycle stage, however it is often supplied by burning timber residues of the manufacturing process. This reduces the demand for fossil fuels, another sustainable feature of wood products.

To ensure transparency, the results for the GWP impact category in the EPD is separated out into CO_2 emissions from burning fossil fuels (the' GWPF' impact category) , and CO_2 emissions from burning timber waste residues, or 'biogenic' emissions (the 'GWPB' impact category). For simplicity, only the total GWP impact category results are reported in this guide.

Timber product	Density (kg/m³)	Cradle to Gate Embodied Carbon kgCO_2-e/m³	Cradle to Gate Embodied Carbon kgCO_2-e/k	Sequestered Carbon kg CO_2/m³	Sequestered Carbon kg CO_2/kg
Surfaced kiln dried radiata pine - untreated	**486**	**-728**	**-1.50**	**-798**	**-1.64**
Surfaced kiln dried radiata pine –LOSP treated (H3.1)	**486**	**-678**	**-1.40**	**-798**	**-1.64**
Finger jointed radiata pine	**475**	**-697**	**-1.47**	**-788**	**-1.66**
Glulam radiata pine	**491**	**-668**	**-1.36**	**-808**	**-1.65**
CLT radiata pine	**500**	**-678**	**-1.36**	**-818**	**-1.64**
LVL radiata pine*	**560**	**-721**	**-1.29**	**-912**	**-1.63**

Figure 19: Cradle to gate Embodied Carbon (modules A1-A3) and sequestered Carbon for New Zealand timber construction products, from WPMA EPD, except *LVL Radiata pine, from Carbon Footprint of NZ LVL, SCION, 2010.

Timber buildings result in another saving in Embodied Carbon over steel and concrete alternatives in this stage too: as they are typically lighter, the foundations can be designed for lower demands, under gravity and seismic load cases. The sub-structure can therefore be smaller in scale. As high mass components, sub-structure elements are often a hotspot for embodied Carbon in this life cycle stage, so reducing the quantity of material used can have a significant impact on the overall building Carbon footprint.

5.2 MODULES A4-A5, B: TRANSPORT, CONSTRUCTION, REPAIR/REPLACE/ REFURBISHMENT

The Modules of these life cycle stages that are associated with embodied Carbon are excluded from the WPMA timber EPD, as they are dependent on particular scenarios, e.g. location of site. They are best modelled at the building level rather than product level.

There are some New Zealand specific data to enable estimates of embodied Carbon in these life cycle stages within the LCAQuick tool (see section 5.4).

5.2.1 Module A4: Transport

This life cycle stage is excluded from the WPMA timber EPD, as the impacts depend on the distance between the place of manufacture of the timber product and the site of the building where it will be used. However these can be determined when the distances are known, using emissions data from freight in and to New Zealand, see Figure 20:

Mode of freight transport	kg CO_2-eq/tonne-km
Road	**0.136**
Rail	**0.028**
Shipping	**0.045**
Domestic air	**5.83**
International air short haul	**1.95**
International long haul	**1.23**

***Figure 20:** Emissions from freight (Ministry for the Environment, 2019. Measuring Emissions: A Guide for Organisations).*

Many Cross Laminated Timber (CLT) manufacturers are located in mainland Europe, and export their products to Australia and New Zealand. The CO_2 emissions associated with shipping 1m^3 of CLT this distance (about 22,000km) is 495 kg CO_2-eq. This value is significant when compared to the emissions from manufacturing CLT, around 140kg CO_2-eq per m^3 according to the WPMA EPD, but is only 3/4 of the total A1-A3 lifecycle stage Carbon impact (-678kg CO_2-eq) when Carbon sequestered by the trees and stored in the timber product is accounted for.

5.2.2 Module A5: Construction

Engineered wood construction systems such as CLT are primarily prefabricated, with the bulk of the construction time, effort and energy happening in a factory environment, rather than on the building site. Prefabricated systems generally require smaller teams, shorter construction periods on site and less construction waste than more traditional methods, especially using 'wet trades' such as in situ concrete or brick and block masonry construction. This results in lower Carbon impacts for prefabricated timber buildings at this life cycle stage, although there is little research that has been done in this area.

5.2.3 Modules B3-B5: Repair/Replace/Refurbishment

Typically structural components shouldn't need maintaining over a typical building lifetime of 50 or 60 years. Structural systems (foundations, frame, ground floor, suspended floors, roof) form the majority of the high mass elements of a building which account for most of the embodied Carbon. Typically the components of a building that need to be replaced over the lifetime are finishes, cladding, fixtures and fittings. The embodied Carbon of replacement components, or emissions associated with repair and maintenance of these is sometimes known as 'recurring embodied Carbon'.

As with any structural elements, timber construction products must be durable for the design life – a requirement of the New Zealand Building Code, clause B2. This is typically ensured with chemical treatment processes: details of their environmental impacts are in Appendix D.

5.3 END-OF-LIFE: MODULES C AND D

The end-of-life of a building covers that period of time and the processes that happen to the constituent materials of a building, including timber, when it is deconstructed or demolished at the end of its useful life.

There are significant issues surrounding the assessment of the environmental impacts of this life cycle stage. For a new building, LCA is carried out at the design stage, and as the typical design life of buildings is 50 years, there is considerable uncertainty on what the market and typical processes will be for disposal and recycling of construction materials that far ahead in the future. However, in order to be a full cradle-to-grave LCA assessment, assumptions need to be made about the potential impacts: this is most commonly done by evaluating the impacts of a number of different possible scenarios, ranging from reuse and recycling to incineration with energy recovery through to disposal into landfill. These are covered in the WPMA EPD and are discussed here.

5.3.1 Modules C1-C2: Deconstruction/Demolition, Transport to Waste Processing

Deconstruction requires a controlled dismantling of the building, effectively a reversal of the construction process, whereby building components are removed, at least partially intact, for reuse in their original manufactured form, or recycled where this is not possible. In contrast demolition implies a forceful breaking down of a building, to produce mostly rubble.

The majority of situations incorporate elements of both deconstruction and demolition so that there is at least some potential for the recovery and reuse or recycling of some of the materials used in the construction of the building.

Like most construction product EPDs, the WPMA timber EPD does not give a value for modules C1 and C2. However with changes to EN 15804 that came into force in June 2019, all new EPDs will need to report a value for these modules. How this will be done for a constituent part of a building is not clear.

5.3.2 Module C3 Scenario: Reuse

Reuse provides the opportunity to use an item again after it has been used. This can be either conventional reuse where an item is used again for the same function, or new-life reuse where it is used for a different function. For building materials, reuse can involve the recovery of largely intact materials, components or building systems for further construction, including the reuse of timber products such as framing, floorboards, windows and doors.

5.3.3 Module C3 Scenario: Recycle

Recycling is the breaking down of a used item into raw materials which are then used to make new items. This is done to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution (from landfilling) by reducing the need for conventional waste disposal, and lower greenhouse gas emissions as compared to virgin material production.

Recycled timber used in construction can come from old buildings, bridges and wharfs, where it is carefully stripped out and put aside by demolishers. The salvaged timber is then sold to merchants who then re-mill the timber by manually scanning it with a metal detector, which allows the timber to be de-nailed and sawn to size. Once re-milled the timber is commonly sold to consumers in the form of timber flooring, beams and decking, and timber salvaged in the demolition of large buildings is increasingly enjoying new life as a feature in new commercial buildings.

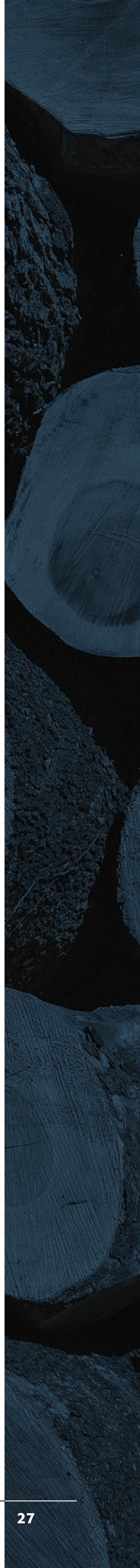
Importantly, when timber is recycled it continues to be a vital store of Carbon, as its useful life is extended beyond the purpose for which it was originally intended. Using recycled timbers is also highly energy efficient as there is no requirement to extract, transport and dry virgin timber, and in some cases the timber need not be re-milled.

Recycled wood packaging and off-cuts are being increasingly used in the manufacture of particleboard. Animal bedding, mulch and composts are also able to utilise the natural moisture-retaining properties of timber.

5.3.4 Module C3 scenario: Disposal with Energy Recovery:

When wood residue from timber processing cannot be recycled, it can be used to produce energy. Wood is a natural material, and the energy created by burning it is biomass energy, a renewable energy.

When wood waste is burned to produce energy, it is assumed to offset the need to burn fossil fuels. This results in a reduction in CO_2 emissions, as burning wood results less CO_2 per unit of energy generated than other fuels, see Figure 21:



Fuel Type	kg CO_2-eq per GJ electricity
Coal	~100
Gas	54
Fuel oil	91
Hydro electricity	4*(includes emissions during construction and distribution)
Wood	2

Figure 21: Net greenhouse gas emissions of different energy sources in New Zealand, including emissions during production, transport and biogenic carbon flows (Scion, Carbon cycling info sheet, 2018).

Wood waste is already being used in New Zealand as fuel for large scale industrial heat processes: wood chips from demolition waste fires the kilns for the production of cement by Golden Bay cement factory in Whangerei, representing up to 30% of the total fuel intake there in 2012.

Many other industries in New Zealand are already using biofuels, including wood, alongside fossil fuels (known as co-firing) to reduce emissions. Companies such as Fonterra have made ambitious pledges to reduce emissions, and eliminate all fossil fuels from their supply chain. To do this, alternative supplies of biofuels will need to be found, and waste wood products could form part of the solution.

5.3.5 Disposal in landfill (with/without energy recovery): Module C4

Disposal to landfill, the process for the disposal of waste materials by burial, is the oldest form of waste treatment. Historically, landfills have been the most common methods of organised waste disposal and remain so in many parts of the world. However, in developed countries with high population densities, such as in Northern mainland Europe, pressure on space for landfilling has led to stringent rules and powerful incentives such as high landfill taxes for diverting waste streams. Landfilling of timber has been banned in several European countries for many years. In New Zealand and Australia, a significant component of Construction and Demolition (C&D) waste is currently placed in landfills.

Scientific consensus on the dynamics of Carbon in wood that is landfilled has shifted over the last twenty years. Early models from the Independent Commission on Climate Change (IPCC) suggested that a large portion of the Carbon in wood would decompose and return to the atmosphere, either as Carbon Dioxide, or, given anaerobic conditions, potentially methane, a greenhouse gas with a much greater global warming potential. This would therefore significantly increase the carbon footprint of wood products, although it can be mitigated by capturing methane gas from landfills and used as a biofuel to replace fossil fuels.

However, it has emerged that these early theories were based on tests carried out using wood samples crushed to a powder, and when more recent research was carried out, using more realistic timber samples, the component of the carbon content in landfilled wood that degrades, known as the Degradable Organic Carbon fraction (DOCf) is much smaller than previously thought, and most of the carbon content will likely remain in semi-permanent or permanent storage, providing ongoing climate benefit.

Ongoing research continues to add to scientific knowledge in this area, however the trend has been for a continuing decrease in the DOCf. The landfill scenario used in the WPMA EPD assumes a DOCf of 0.1%, based on experimental research specifically for Radiata pine. This essentially means there is no Carbon emissions or GWP impact for this scenario. However, should a more conservative DOCf value be taken, the assumptions on the split between CO2 and methane in the resulting emissions are described in the EPD.

5.3.6 Module D: Benefits and Loads beyond the System Boundary

As discussed in Section 4.4, this module reports Carbon emissions saved (i.e. a negative number) in another building LCA (i.e. outside the system boundary of this building LCA) as a result of recycling or reuse of material/elements from this building. In the case of the GWP of wood construction products, this is typically due to Carbon emissions from fossil fuels that have been avoided by burning waste wood products instead and recovering the energy, in the form of heat or electricity.

5.3.7 End –of-Life scenario comparisons

The WPMA EPD for New Zealand timber products provides data for Modules C3 and D for each of the end-of-life scenarios as outlined above (Module C4 is used for landfill disposal instead of Module C3).

To illustrate the relative significance of these different scenarios over the whole life, Figure 22 illustrates the total GWP impact over the life cycle stages for $1m^3$ of untreated sawn kiln dried Radiata pine, based on the WPMA EPD data.

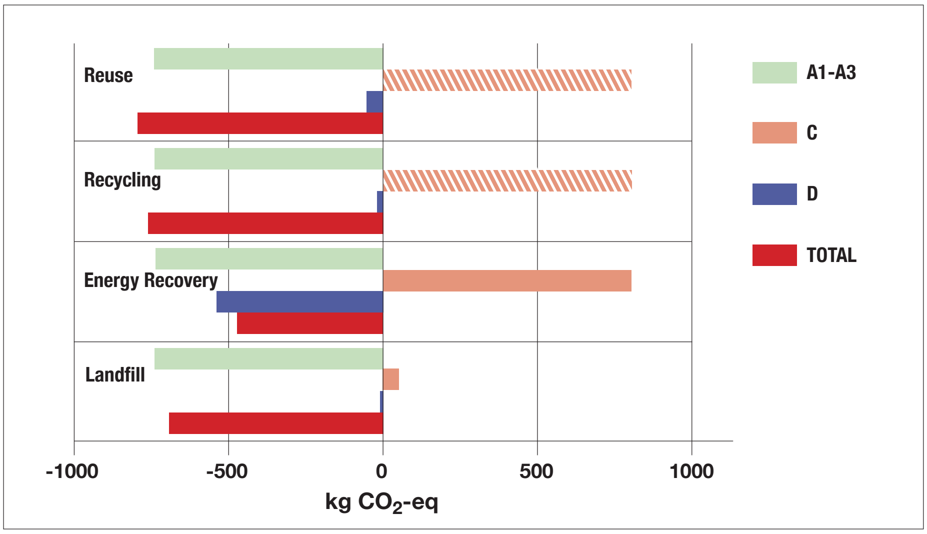


Figure 22: Life cycle embodied Carbon for different End-of-Life scenarios: modules A1-A3, C3/4 & D for $1m^3$ untreated sawn kiln dried radiata pine, WPMA EPD

The Module C values for the reuse and recycling scenarios are hatched, as they represent the flow of biogenic carbon that crosses the system boundary, when wood from one product is used to form another. The Carbon is still stored within the wood itself and there are no emissions of CO_2 to the atmosphere, and so these values have not been included in the total impact for these scenarios. The C3 values must be reported in the EPD and are still shown here, as they are required to ensure that the flow of biogenic Carbon is correctly accounted for in the LCA of products which use the recycled wood, ensuring the Carbon storage benefit can still be recognised in the future product life cycles. However including these values in the total life cycle impact applies an artificial emission for the sake of future products, which may well not result in emissions to the atmosphere within the 100-year timeframe that LCA studies are typically limited to, particularly for solid wood products used in construction.

Some methodological approaches require Module D to be reported outside the total impact, however they have been included here to be consistent with the approach used by assessment tools such as GreenStar. The Module D value shown for the Reuse scenario is the biogenic GWP value, rather than the GWP value as shown in the EPD: the GWP value as shown in the EPD for this has been identified as an anomaly and will be corrected in future updates of the EPD.

Note that this approach has been discussed with and deemed to be appropriate by thinkstep-anz, the LCA practitioner who authored the WPMA EPD.

Of particular note is the large negative total for the landfill scenario. This is due to the very low DOCf value used (0.1% - see section 3.3.4), and minimal processing activity associated with landfilling, resulting in minimal emissions at this lifecycle stage.

Energy recovery has a large negative value in Module D, which counters the positive value in Module C. This is because the energy recovered from incinerating the timber is assumed to be substituting the use of fossil fuels, typically in large scale industrial heat processes, such as firing the kilns for the production of cement by Golden Bay Cement factory near Whangerei. Note that the size of the module D 'credit' depends on the fuel being substituted or offset by incinerating the wood waste. Whilst offsetting fossil fuels will be one of the most common outcomes, the credit may be reduced if a less Carbon-intensive fuel is being offset. The release of carbon from incinerating the wood waste is equal to the Carbon sequestered by the growth of the tree (included in A1-A3), but the offset of emissions from other fuels will typically result in a net Carbon benefit over the life cycle.

All 4 End-of-Life scenarios have a similar whole-of-life GWP impact when considering the A1-3, C and D Modules, reducing the potential of mispresenting whole-of-life Carbon of timber construction products by assuming a particular scenario at the design stage. All are large negative values in total across these Modules, considered to be the most significant over the life cycle. This gives further justification for the inclusion of the Carbon storage benefits of construction wood products, provided that this wood is from sustainably managed forests and that new trees are replanted after felling.

5.3.8 Reuse of timber buildings

In addition to reuse of wood in construction at the product scale, entire buildings made from wood can lend themselves to reuse. Examples of this can be seen in New Zealand in the residential and educational sector, with single storey dwellings and classrooms buildings frequently being repurposed, and often transported large distances by road. The Carbon benefits of this are significant as a result of avoided emissions from disposal and processing of additional raw material into new products.

Figure 23: Timber framed residential building in Christchurch being relocated for reuse (K. Symons).

The use of lightweight floors on shallow foundations in timber framed buildings means that they are also adaptable to climate change. These floors lend themselves well to being raised up above ground levels during the building's life, as may be required to adapt to future changes in ground water levels, thus improving the building's resilience.

6. SUSTAINABLE BUILDING INDICATORS AND RATING TOOLS

The Carbon footprint of timber construction products is only one part of the total environmental impact of any building project.

There are many indicators and rating tools that aim to assess and communicate the sustainability of buildings in a single overall rating or score.

In 2018 Bionova completed a systematic review over 150 green building assessment systems that are used around the world and showed that of these, 105 included direct measures for embodied Carbon, and that this number has doubled over the last 5 years.

BREEAM, LEED and Greenstar are the three best known sustainable building rating systems in New Zealand, and LCAQuick is a New Zealand specific building LCA tool. How they each recognise the Carbon benefits of timber is discussed in the following sections.

6.1 BREEAM

BREEAM (Building Research Establishment Environmental Assessment Method), originated from the UK in 1990, making it the longest established method of assessing and rating the sustainability of buildings. It is used in more than 70 countries, with several in Europe having gone a stage further to develop country-specific BREEAM schemes, including Spain, Norway and Sweden. The assessment tool can be applied to buildings, infrastructure and communities, new construction and refurbishment projects, and in-use operations. It measures sustainable value in a series of categories, including energy, land use, pollution, water, waste and materials. Points are scored in each category under a credit system, and the total gives an overall rating, ranging from Pass, through to Excellent and Outstanding.

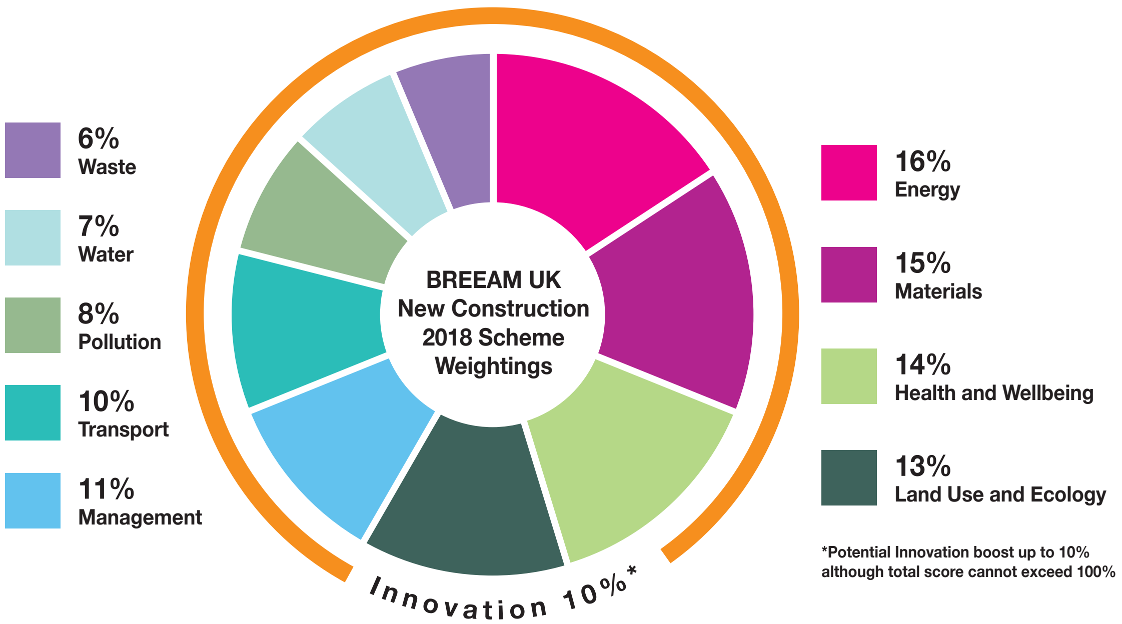


Figure 24: BREEAM Assessment Framework, materials make up 15% of the total score.

The materials category has included an assessment of the environmental impact of construction products in buildings for over 20 years. Initially this was done using generic values for building elements, such as concrete slab floors, or timber framed walls, awarding scores in the MAT01 credit for their relative environmental impact, which included their embodied Carbon.

With the growing understanding of LCA in the construction industry, and a much greater coverage of EPDs for construction products, the 2018 version of BREEAM for new construction projects requires a full building LCA to achieve a MAT01 credit score.

Changes in the 2018 version mean now a project can score up to 10 credits in MAT01 for carrying out an LCA in most BREEAM schemes: this is equal to the difference between final rating levels, and so can mean the difference between a final result (e.g. shift a building rating from 'Very Good' to 'Excellent'). It is therefore a significant credit, and has a relatively low cost impact in the design stage, so is a popular credit to look to score well in. This boost in points for LCA in the MAT01 credit has driven the development of powerful LCA software tools that take complex methodologies (such as EN 15804) and use large LCA datasets , and put them behind a user-friendly front end (OneClickLCA being one example), thereby making the use of LCA in construction more widespread.

Initial points in MAT01 are earned by simply carrying out an LCA, irrespective of the results, using an accredited tool, of which there are now many available. Other points can be earned by using EPD data for the calculation, and including the materials that you are using the EPDs for in the project specification, to ensure that there are no changes further on in the design process, for example with contractors switching to alternative products which may have different embodied Carbon values. Subsequent points are earned by demonstrating a saving in embodied Carbon through comparing cradle-to-gate embodied Carbon of an optimised design against a baseline design. This is where the low Carbon benefits of timber construction products will be recognised and should score highly in the MAT01 credit.

There are other credits in the BREEAM assessment that timber will score well on: MAT03 considers responsible sourcing of construction products, and so in the case of timber buildings, certification indicating a sustainable and responsible supply chain, such as FSC or PEFC (see Appendix C) will score points.

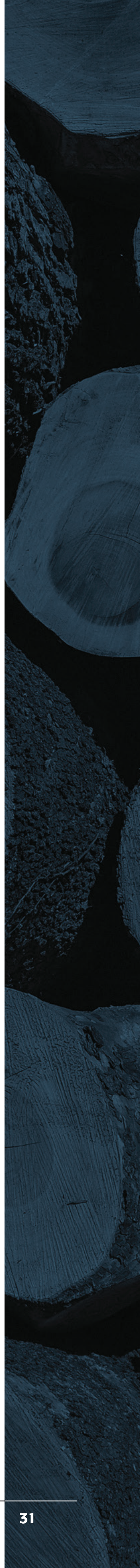
6.2 LEED

LEED (Leadership in Energy and Environmental Design) was developed by the US Green Building Council in the early 1990s, and still has a North American focussed zone of influence, however like BREEAM it is used all around the world today. Also like BREEAM it has expanded from one standard to a comprehensive system of interrelated standards, covering aspects from the design and construction of new buildings and the maintenance and operation of existing buildings and can also be applied to the development of whole communities. Certification results start at "Certified", and move through Silver, Gold up to Platinum, depending on the score out of 100 base points available across six credit categories, one of which is "Materials and Resources".

In the recently revised version 4.1 of LEED, the points available for the MRc1 credit increased to 4. One credit is earned by carrying out an LCA and no performance comparison is required. The further three credits are obtained by demonstrating a 5%, 10% and 20% reduction in the global warming potential impact categories (i.e. embodied Carbon) from a baseline design. Software tools like OneClick LCA have automated the process of creating a baseline design and comparing against in, making achieving these points easier.

MRc2 also offers credits for using EPDs, in a similar way to BREEAM.

Like BREEAM, there are no specific credits to be obtained by using timber, but the intrinsic lower embodied Carbon of timber construction products should score highly in the LEED framework. Also like BREEAM there is a trend to increasing emphasis on LCA and Carbon assessment in this tool, with more credits in this area currently in development to be included in the next version of LEED.



6.3 GREENSTAR

The GreenStar environmental rating system was introduced in New Zealand in 2007 and is adapted from the Australian GreenStar system . The New Zealand version is developed and maintained by the New Zealand Green Building Council. In the same way as BREEAM and LEED, points are earned in different environmental impact categories such as Energy, Water, Emissions and Materials and totalled to give a Green Star certified rating between 0-6, see Figure 25.

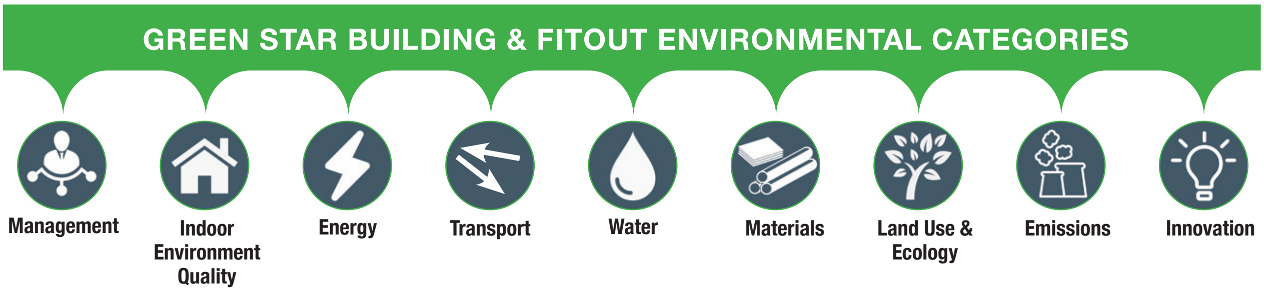


Figure 25: GreenStar environmental impact categories.

GreenStar is used for any building typology, although it is noted that HomeStar is a separate tool intended for use with residential buildings.

Again like BREEAM and LEED, a GreenStar assessment can be carried out on existing buildings, whole communities as well as new buildings, with the latter assessed using the 'Design and As Built NZ' version of the rating system. In this version of the tool, out of a total of 100 points, there are 14 points available in the materials category. Of these, 7 are associated with Life Cycle Impacts, 3 with Responsible Building Materials, 3 with Sustainable Products and 1 with waste.

There are two ways to achieve the 7 credits available in the Life Cycle Impacts category. A full LCA can be carried out for the building using the GreenStar LCA calculator. Results are compared against a reference building, with points awarded for the extent of environmental impact reduction (including operational and embodied energy and Carbon.

Additional points awarded when the project team can demonstrate the LCA has informed the design process, or report additional impact categories.

Alternatively, the 7 credits can be achieved by meeting prescriptive requirements for the use of concrete, steel, timber and reuse of structure of façade materials on the project. For structural timber, 4 points are available. The first is awarded when all structural timber is responsibly sourced (this is a minimum requirement), the next three are awarded when 30%, 70% and 90% of the building's internal area is supported by a timber structure. Examples of timber products that qualify are CLT, LVL, glulam and sawn timber used for structural purposes. Use of timber product such as plywood and MDF in non-structural applications, as well as timber formwork does not qualify. The guide for the Green Star Design and As Built tool states that these points are awarded on the basis that *"buildings with a primary timber structure reduce the use of traditional structural materials, namely concrete and steel. This results in a physically 'lighter' building with overall reductions in embodied environmental impacts."*

In addition, a timber building should typically be awarded a single credit for responsible sourcing, assuming the timber is either from a recognised forest certification scheme (such as FSC), or is reused. The use of materials that have EPDs, which is the case now for most timber products in New Zealand, thanks to the recent WPMA collective EPD, also offers timber buildings the opportunity to gain points in the Sustainable Products category. The use of engineered timber products that are typically prefabricated in a factory environment, such as CLT, should also qualify for the single point in the Construction and Demolition Waste category, as they should be able to demonstrate that construction waste is reduced when compared with a typical building.

GreenStar appears to be the only example of a mainstream rating system awarding points specifically for the use of timber, in lieu of submitting a more detailed (and onerous) LCA.

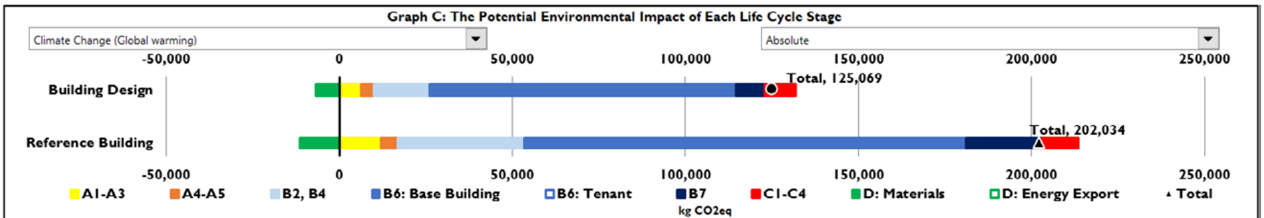
6.4 LCAQUICK

LCAQuick (currently v3.3) is a freely available, excel based tool for completing LCAs on whole buildings in New Zealand. It has the capability to take material quantities directly from a building model in a BIM software package such as Revit, as well operational energy use, either simulated, measured or estimated, to complete a full LCA. The tool combines this information with a comprehensive LCA database, to provide results for a number of environmental impacts, including GWP (embodied and operational Carbon). The LCA is carried out in accordance with the EN 15804 standard, and using high level data about the building's location, size and other characteristics, it covers all stages of the life cycle: cradle to gate (Modules A1-A3), transport (A4), construction (A5), operation and maintenance (B2, B4, B6, B7), end of life (C), and benefits and loads beyond the system boundary (Module D).

Environmental impact data, including for Carbon emissions are taken from EPDs, Australasian where available, but also other EPD schemes, such as The International EPD® System. Where data from EPDs are not available, generic data from the EcoInvent LCA database and other sources are used. The database is updated on an annual cycle, and is therefore able to capture data that are more representative of the NZ context as EPDs from manufacturers in this region become available. Detailed functionality is built into the tool to automate calculations for the quantities such as the volume of water that will be used in washing activities, or the materials used in common window assemblies, from which environmental impacts can be derived.

The format of the results (see Figure 26) are designed to highlight building materials or components with the greatest impacts in each indicator category (including Carbon emissions), and in the format used for GreenStar assessments.

Reference buildings are included the tool for offices, stand-alone residential, medium-density housing and an apartment building, enabling the performance of the building under assessment to be compared with a standard benchmark.



Life Cycle Stage	Design	Reference	% Diff.	Life Cycle Stage	Design	Reference	% Diff.
A1-A3: Product stage	6,277.73	11,992.44	-91.0%	B7: Operational Water Use	8,258.40	21,902.40	-165.2%
A4-A5: Construction process stage	3,716.66	4,965.40	-33.6%	C1-C4: End of life	8,936.02	10,533.45	-17.9%
B2: Maintenance & B4: Replacement	16,075.12	36,542.79	-127.3%	D: Materials	-6,758.93	-11,484.71	-69.9%
B6: Base Building Operational Energy Use	88,563.61	127,582.24	-44.1%	D: Energy Export	0.00	0.00	
B6: Tenant Operational Energy Use	0.00	0.00		D: Total - the benefits and loads the beyond system boundaries e.g. reuse, recovery, recycling and energy generation/export potential after onsite consumption.	-6,758.93	-11,484.71	-69.9%
B6: Total Operational Energy Use	88,563.61	127,582.24	-44.1%				
Total: Sum of all life cycle stages including module D. For commercial buildings, this includes base build and tenant energy use. For residential buildings, this includes plug loads.					**125,068.6**	**202,034.0**	**-61.5%**

Figure 26: Example of the results output from LCAQuick for the GWP environmental impact category.

Updates to the tool are made regularly, with v3.4 expected in March 2020, and BRANZ are also developing tools to look specifically at the embodied Carbon of residential buildings.

LCAQuick is the tool which combines all the elements of a whole-building, whole-of-life framework developed by BRANZ. Each element of the framework (information, reference buildings, data, indicators) is a useful resource on its own.

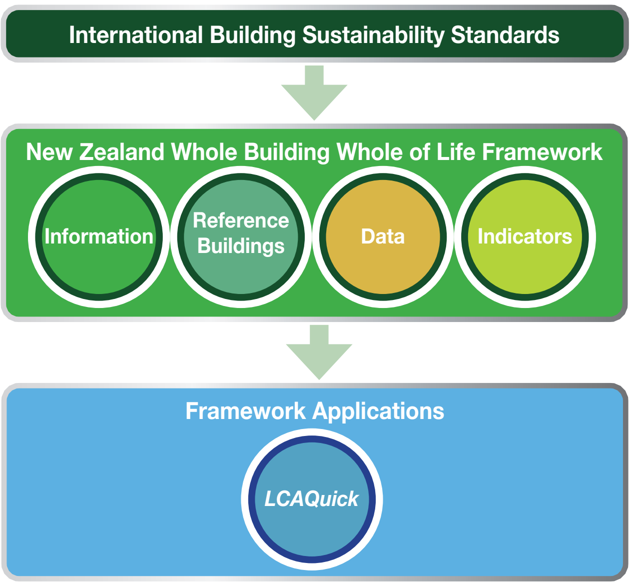


Figure 27: Diagrammatic representation of the BRANZ Whole-building, Whole-of-Life framework

The data element of the framework contains a collection of valuable resources specific to New Zealand, including datasets on transport, construction waste, end-of-life and New Zealand grid electricity, enabling the evaluation of impacts at stages A4, A5 and others that are often omitted from building LCAs.

The embodied Carbon and energy data has been compiled into a comprehensive database called BRANZ CO_2NSTRUCT. It is not a full Life Cycle Inventory, covering only the cradle-to-gate life cycle stage, and the environmental impact categories of energy use and greenhouse gas emissions (kg CO_2-eq), but nevertheless is an extremely useful resource for Carbon footprinting and embodied Carbon calculations for buildings in New Zealand.

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6.5 ZERO CARBON CERTIFICATION

According to the International Living Future Institute (ILFI), their Zero Carbon Certification is the first worldwide Zero Carbon third-party certified standard to fully account for the impacts of a building's Carbon emissions. There is a strong focus on building operational energy efficiency, that can be achieved through the combination of building design performance and the use of renewable energy, and a project must demonstrate net zero Carbon operations based on a twelve-month performance monitoring period. But in addition, in order to obtain the ILFI Zero Carbon Certification, a project must also account for the total embodied Carbon impact from any new construction materials, and demonstrate the mitigation of that through a one-time Carbon offset from an approved source. New projects must also demonstrate a 10% reduction in the embodied Carbon of the primary materials of the foundation, structure, and enclosure, compared to an equivalent baseline.

The total embodied Carbon of the project must be calculated over a 50-year lifespan, by using an approved LCA tool, including the estimated Carbon impact of all 'as-built' construction materials, and processes related to the construction of the building's structure, envelope, foundation and interior. From an embodied Carbon perspective, projects may claim a benefit from substituting a Carbon storing product such as wood for one that is Carbon emitting (e.g. concrete, steel).The Embodied Carbon Guidance provided by ILFI suggest that *"the specification of approved third-party certified sustainable harvesting strategies may be claimed as an additional product-specific embodied Carbon reduction"* and that *"the Carbon sequestering benefits of a qualified product must be described and calculated separately from the embodied Carbon of the material itself, even if it is not clearly distinguished in the EPD"*. The Forest Stewardship Council (FSC) certification is recognised as an approved sustainable harvesting standard, while alternative certification programs or verification standards need to be vetted and approved by the ILFI prior to their use. EPDs provided by qualified programme operators on behalf of product manufacturers or industry organizations should be used to source products' Embodied Carbon data.

7. REGULATORY DRIVERS

7.1 NEW ZEALAND ZERO CARBON ACT

Figure 28: New Zealand Prime Minister, Rt Hon Jacinda Ardern, and Climate Change Minister, Hon James Shaw, sponsor of the the Zero Carbon Bill.

On November 7th 2019, the New Zealand parliament voted to enact the Climate Change Response (Zero Carbon) Amendment Bill. Known as the Zero Carbon Act, it commits New Zealand to becoming Carbon neutral by 2050. By this date, annual greenhouse gas emissions (with some exceptions for methane emissions from agriculture) are to be reduced as close to zero as possible, with any residual emissions to be offset by sequestering Carbon.

Whilst the New Zealand forestry industry will clearly have a role to play in offsetting to meet this target, buildings are arguably low hanging fruit in the search for emission reductions. As set out at the start of this guide, to date they have not received as much attention in New Zealand as emissions from agriculture or transport.

It should be noted that many regional jurisdictions within New Zealand have set emission reductions targets that are more ambitious than at the national level. For example Christchurch City Council aims for their district to have net zero greenhouse gas emissions by 2045. As national and local governments search for means of achieving these targets, the emissions associated with constructing buildings can be expected to come under scrutiny. The construction industry needs to be ready to expand in the direction of low Carbon construction materials such as timber, in order to play its role in meeting emissions reduction targets.

7.2 NET ZERO CARBON BUILDINGS

In the same way that whole countries set out to be Carbon neutral, within the context of reducing emissions from buildings, the concept of achieving net zero Carbon buildings is becoming more prevalent.

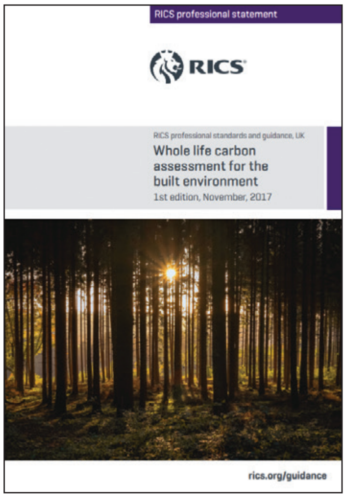
A net zero Carbon building is one that offsets as least as much Carbon as it emits over its lifetime, including operational and embodied Carbon emissions.

The New Zealand Green Building Council (NZGBC) launched a Zero Carbon Road Map for Aotearoa's Buildings in 2019.

Their proposals include prioritising the use of plant based materials such as timber where they can be substituted for steel and concrete, to reduced embodied emissions from buildings. They proposed a number of regulatory changes to achieve the goal of all buildings to be zero Carbon by 2050, including changes to the main regulation instrument for construction in New Zealand: the Building Code.

The NZGBC proposals are aligned with the World Green Building Council 'Advancing Net Zero' project. Accordingly, many other countries, such as the UK and Canada, are developing frameworks to achieve the same objectives. For example, in 2019 the UK Green Building Council developed a framework definition for Net Zero Carbon buildings, which includes technical requirements for whole life Carbon assessments of buildings. These are in line with the methodology set out in the 2017 Royal Institute of Chartered Surveyors (RICS) Professional Statement: 'Whole life Carbon Assessment for the Built Environment'.

Although not regulation yet, the requirements for whole life Carbon Assessment as set out in the Professional Statement are mandatory for members of the RICS. The Statement contains detailed requirements for embodied Carbon assessments, including accounting for sequestered Carbon stored in timber construction products that are in line with the methodologies set out in this guide, and in accordance with international standards. The low Carbon characteristics of timber are therefore set to become more visible, as methods of measuring embodied Carbon are heading towards becoming mandatory in professional practice.



7.3 LEGISLATIVE REQUIREMENTS FOR EMBODIED CARBON

Figure 29 provides a summary of just some examples of legislative and other requirements that have been adopted in recent years with the goal of reducing embodied Carbon in construction, and is by no means an exhaustive list.

WHAT?	WHERE?	WHEN?
Requirement for a calculation of embodied Carbon for a building consent. **A mandatory cap on environmental impact of materials (including Carbon but other impact categories as well) – first in the world.**	**The Netherlands**	**Since 2013.** **Cap has been mandatory since 2018.**
Carbon footprinting methodology to become mandatory for new building consents. Currently run as a pilot programme 'Energie Positive & Reduction Carbone', comprising regulatory method and tools, issued by central government.	**France**	**To become mandatory in 2020.**
Voluntary certification system Futurebuilt: a method to reduce life cycle Carbon by 50% compared with national reference values, verfied by a 3rd party.	**Norway**	**Since 2009.**
Developers seeking a rezoning application need to include the reporting of whole life embodied Carbon.	**Vancouver, Canada**	**Since May 2017.**
Whole-building life cycle assessment is required for new government building projects, with points awarded based on performance against a benchmark. **Private-sector voluntary green building program with a similar life cycle assessment benchmark approach. National life cycle assessment /EPD database is used widely and a free, national, whole-building life cycle software tool.**	**Germany**	**Since 2010.** **Has been continually developed since 2009.**

Figure 29: Examples of legislative and other requirements for the reduction of embodied Carbon in construction.

7.4 WOOD FIRST POLICIES

'Wood First' or 'Wood Encouragement' policies are where building consenting authorities create a 'presumption in favour' of using wood in new buildings. Policy wordings may vary, but a typical example may be that in order to receive a consent, a building must be constructed primarily of timber products, or provide compelling evidence that options were considered and not progressed for good reason. It is a controversial policy intervention, as free markets don't typically allow regulators to 'pick winners', which is often how Wood First policies are seen by central governments. However, it may be an effective action to encourage greater use of wood as a construction material, especially if supported by a cash incentive through a Carbon encouragement grant of some sort.

New Zealand led the world in Wood First policies. In 2005, the Labour government provided $18 million for the Forest Industry Development Agenda (FIDA), promoted by Hon Jim Anderton, then Minister of Forestry. Part of this FIDA funding was $8 million for Market Development. Another $2 million was earmarked to promote excellence in wood design in the education and construction sectors.

The FIDA funding led to development of a "Wood First Policy" about 2007, which required the designers all government funded new buildings to consider the use of wood as the main structural material. There was also a financial subsidy to encourage construction of exemplar buildings.

$1 million of this government subsidy was put towards the design and construction of the Nelson & Marlborough Institute of Technology (NMIT) Arts and Media building in Nelson, after a national design competition, see Figure 30. This was completed in 2011, being the first building to use the Pres-Lam technology developed at the University of Canterbury. The building became a catalyst for the design and construction of a number of similar timber buildings elsewhere in New Zealand and overseas.

Figure 30: The NMIT building made use of an innovative post-tensioned timber frame, with seismic resilient technology .

The Wood First policy was stopped in 2008 by the new government after the election that year.
A similar, but regional, Wood First Policy was adopted by Rotorua Lakes Council in 2015. They were followed by Gisborne District Council who adopted their own in 2018.

In the lead-up to the 2017 elections, both the Labour Party and the Green Party manifestos contained pledges around Wood First, but as of early 2020, no policy measures of this kind have been implemented. The current government has undertaken measures to support the use of wood in construction, including:

- publication of Sustainable Construction guidelines for government procurement (which includes specific information on the benefits of wood in construction),
- significant Provincial Growth Fund support for wood processing,
- $2 million of funding for a 4 year mid-rise wood construction programme to include the construction of two reference buildings using CLT to use as industry case studies.

New Zealand's 2007-2008 Wood First policy was noticed by governments in Canada, Japan, and Australia, leading to similar policies in those countries and others, as shown in Figures 31 and 32.

COUNTRY	REGION	POLICY OUTLINE
Canada	**British Colombia**	**A 3 year plan launched in November 2019 to make BC a leader in innovative timber construction, with a budget of CAN$2.8 million for 2019/2020.**
Japan	**Nationwide**	**Promotion of use of Wood Materials for Public Buildings became law in 2010, obligating national and local governments to use wood for their buildings under 3 storeys.**
Australia	**2 States of, 2 Local Government Authorities and 16 local councils, see figure 32**	**Since 2014, State and local government building project specifications include a clause on the requirement to consider the use of wood in the construction and fit-out of buildings and other infrastructure where it can meet a number of requirements, including value for money, provision of quality and compliance with all relevant standards and legislation.**
France	**Nationwide**	**From 2022, all new public buildings to be built from at least 50% timber or other natural materials.**

Figure 31: Examples of Wood First policies outside New Zealand.

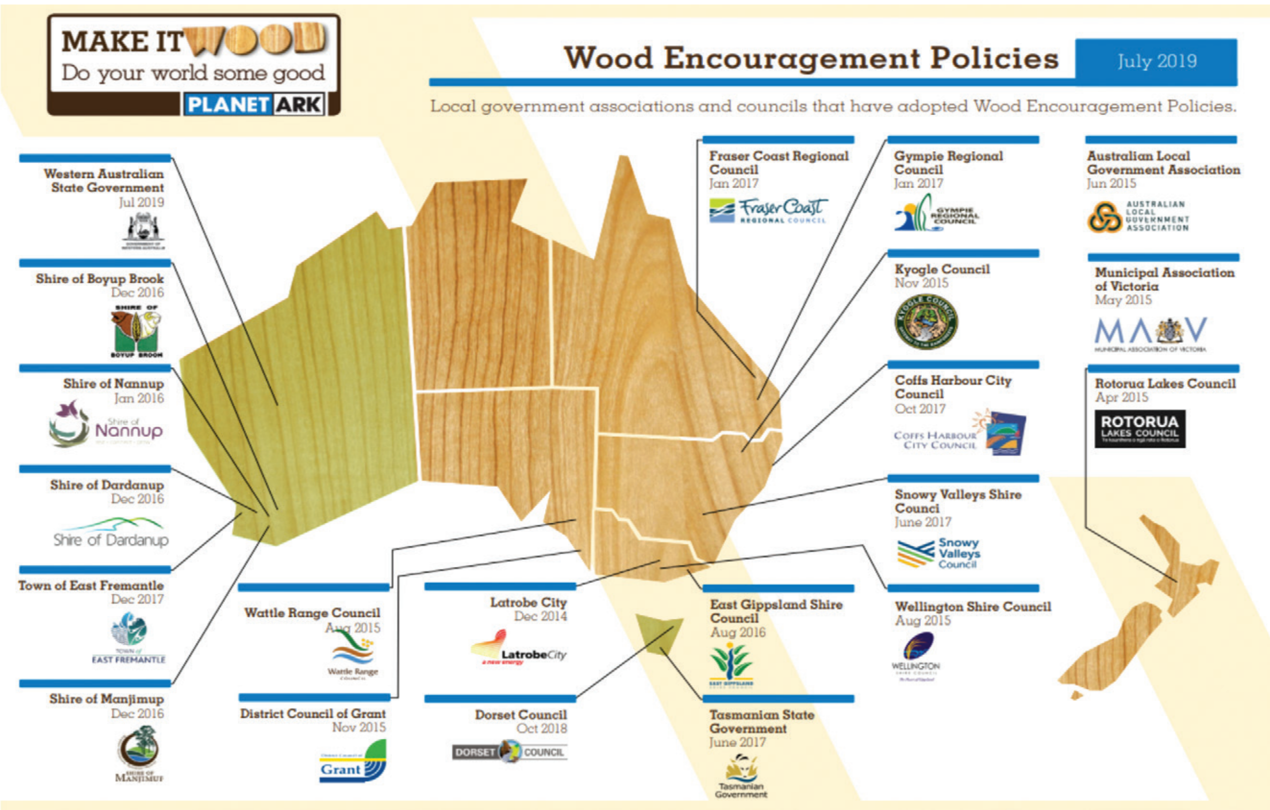
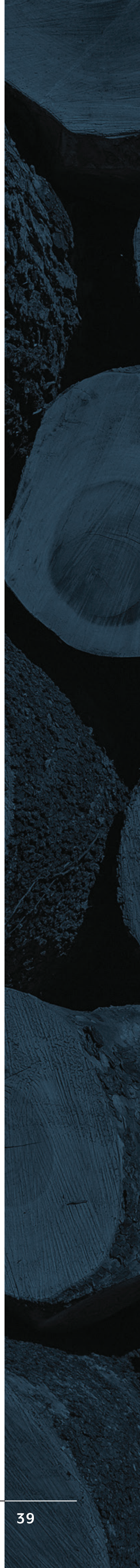


Figure 32: Wood Encouragement Policies adopted in Australia since 2014.



7.5 CARBON CREDITS FOR TIMBER BUILDINGS

The New Zealand Timber Design Society (TDS) has proposed that Carbon credits could be paid to owners of new timber buildings, as one of the ways to recognise the value of the Carbon stored in the wood, and encourage the design of timber buildings using renewable materials. The TDS proposal would theoretically support of the government's One Billion Trees programme, to encourage more forestry on marginal lands and support regional economies by providing a larger domestic market for timber products. Each year New Zealand exports 22 million tonnes from a total of 36 million tonnes (about 61%) of logs produced. Of the remaining 14 million tonnes that are processed in New Zealand into products such as sawn timber, LVL, structural panels and paper, about 60% of these are exported. Thus only around 15% of the output from New Zealand forests ultimately ends up in timber products used in the domestic construction industry.

This guide has shown how the biogenic Carbon stored in forests remains in the resulting wood and wood products after the trees are harvested, extending the life of the pool of Carbon. The wood components of a new timber building can store significant amounts of Carbon for many years, until the wood eventually decays or is burned.

To enhance the Carbon benefits of forestry, the owners of new buildings could be financially encouraged to use wood rather than other structural materials.

The Carbon benefits of timber construction can be quantified, and have been explained in this guide. It has been shown that as about half the dry mass of wood used in construction is biogenic Carbon, 1 m^3 of Radiata pine sequesters around 800kg of CO_2. A typical 200m^2 New Zealand home contains around 30m^3 of Radiata pine framing, storing around 24 tonnes of CO_2. The NMIT building contains 460m^3 of LVL, storing around 420 tonnes of CO_2. (Carbon credits and Carbon taxes are usually related to tonnes of CO_2-eq, not to tonnes of Carbon).

Rather than involving the accounting complexities of the Emissions Trading Scheme (ETS), a simpler model could be to base any financial incentive paid to the building owner on the amount of Carbon stored in the wood. The money could be from a government fund, or from other sources such as tax incentives or reductions in rates or consenting fees.

A one-off payment to building owners at the time of construction may be easier to administer than a long-term Carbon compliance system.

Such schemes already operate elsewhere in the world, such Germany, where owners of new commercial buildings in Hamburg get paid €0.8 for each kg of timber used in construction. Even small financial incentives are capable of tipping the balance towards timber for many prospective building owners, and could have the potential to increase take-up of timber in construction to a greater degree than 'Wood First' policies.

APPENDIX A: CALCULATION OF SEQUESTERED CARBON IN WOOD PRODUCTS

There has been a change over time on how Carbon that has been sequestered by trees is accounted for in Carbon footprints of the resulting wood products. Previously there was some debate as to whether including the significant beneficial effect should be included in EPDs and other quantitative assessments of timber construction products.

However now the inclusion of sequestered Carbon in timber in the Production life cycle stage (Module A1-A3) is accepted as standard practice, and in the June 2019 update of EN 15804, it has become a requirement for EPDs complying with European EPD system, under clauses in the standard EN 16485: Product Category Rules for wood and wood-based products for use in construction. It is only valid where the Carbon neutrality of the biogenic Carbon can be assumed, i.e. the forests from which the timber is sourced is managed sustainably and does not result in the degradation of forest Carbon pools. EN 16485 states that this assumed to apply when the wood originates from forests which are operating under established certification schemes for sustainable forest management, such as FSC or PEFC.

The standard EN 16449:2014 provides a calculation method to quantify the amount of atmospheric CO_2 based on the biogenic Carbon of timber products, forming the basis for the Carbon storage benefits included in the production stage of the life cycle embodied Carbon, as reported in EPDs for timber products.

The calculation as presented in the standard is as follows:

$P_{CO2} = 44/12 \times cf \times (\rho_W \times V_W)/(1+\omega/100)$

Where:

P_{CO2}: biogenic Carbon, i.e. the potential amount of CO_2 that could be emitted to the atmosphere at the end-of-life stage, and equivalently, the amount of CO_2 that has been removed from the atmosphere during the tree's growth and stored in the timber product(kg)
cf: carbon fraction of woody biomass (dry mass) of the product, 0.5 is the default value
ω: moisture content of the product (%)
ρ_W: density of the woody biomass of the product at that moisture content (kg/m^3)
V_W: volume of the product at that moisture content (m^3)

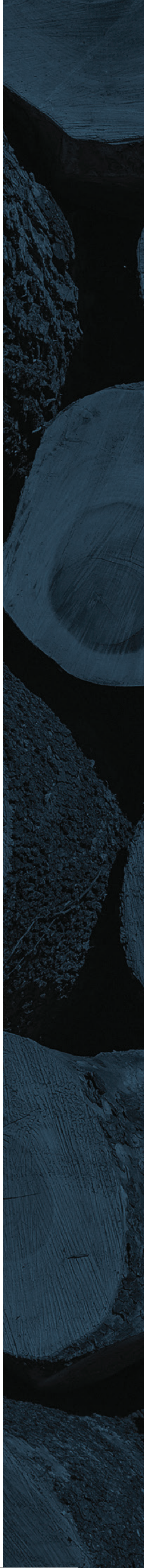
44/12 is the ratio of atomic weights of Carbon Dioxide and Carbon: for every kg of biogenic Carbon, 44/12=3.67 kg of Carbon Dioxide has been removed from the atmosphere.

The Carbon fraction of woody biomass is based on the composition of timber from cellulose, hemi-cellulose, lignin and extractives. Although the 0.5 figure seems simple, research shows that for Radiata pine, it is accurate to 2 significant figures for the wood from the vast majority of forestry sources in New Zealand. In fact there is greater uncertainty over the exact value for the moisture content for a timber product than the Carbon content of the dry mass of that product.

Unlike some other EPDs for timber products, the WPMA EPD does not present separately the negative value calculated for Carbon that has been sequestered in the timber. It does however give the density and moisture content of each of the 5 product type it covers, and so using the calculation method shown above, and assuming a 50% Carbon content of dry mass, the Carbon sequestered in a functional unit (1m^3) of each of the products are as follows:

Product type	Density (kg/m^3)	Moisture content (%)	Carbon content (%)	Sequestered Carbon (kg CO_2-eg/m^3)
Sawn, kiln dried timber	488	11.6	50	-802
Surfaced, kiln dried timber	486	11.6	50	-798
Finger-jointed timber	475	10.5	50	-788
Glue Laminated timber (Glulam)	491	11.4	50	-808
Cross Laminated timber	500	12	50	-818

Figure A1: Calculating the Carbon sequestered in New Zealand timber products (WPMA EPD, 2019).



APPENDIX B: LIFE CYCLE ASSESSMENT – FURTHER DETAIL

B1 LIFE CYCLE ASSESSMENT STANDARDS

LCA is a complex and highly codified process. There are many international standards that define how LCAs are carried out, and some differ in how rules are applied when calculating impacts within system boundaries. However ISO standards 14040:2006 and 14044:2006 "Environmental management - Life cycle assessment - Principles and framework" and "Requirements and guidelines" underpin most robust LCA studies. According to these standards, the stages of LCA are set out as below:

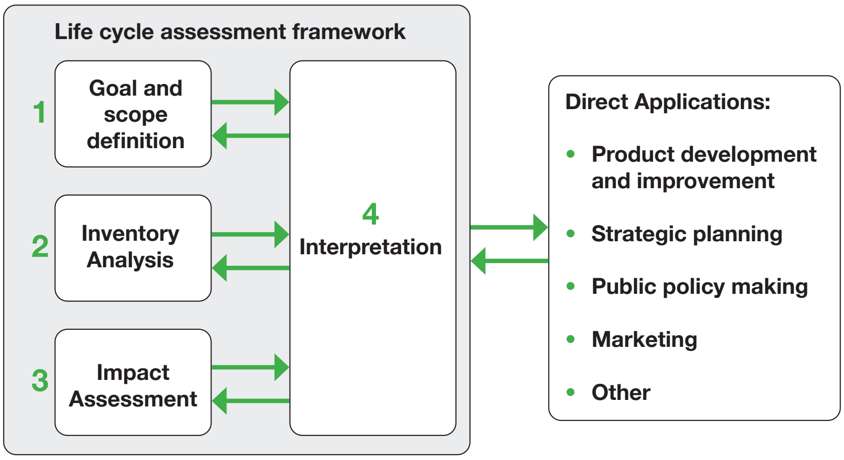


Figure B1: Life Cycle Assessment framework as set out in ISO 14044:2006.

- Goal and scope definition: Before starting an LCA, it's important to define a clear goal and scope of study. This will be used to select a robust calculation method
- Inventory analysis: Once the goal, scope and method have been determined the important stage of inventory analysis can begin. Primary data is from the supply chain, or the most robust data in the literature is collected. The consumption of all materials and energy and creation of waste associated with the product (system) needs to be understood. This data is then used to build a sophisticated LCA model.
- Life cycle impact assessment: With the data collected and a model built, results can be produced. Any number of LCA impact categories can be considered, around 10-20 is typical, including energy, Carbon, water, toxicity, eutrophication, acidification, metal depletion and more.
- Interpretation (conclusions and recommendations): This is the key output of the life cycle assessment. The results will be analysed in detail to determine the impact hotspots and the key environmental impact categories. These can then be used to make recommendations for improvement.

To achieve maximum credibility a peer review is recommended.

Although there are some freely available LCA data sources for embodied Carbon and energy (such as the Inventory for Carbon and Energy in the UK, Nebel, Wittstock and Alcorn (2009) and BRANZ CO2NSTRUCT in New Zealand), typically a full LCA is carried out by private consultancies as a service on a commercial basis. They typically use LCA software tools such as GaBi and SimaPro, which have their own in-built data inventories.

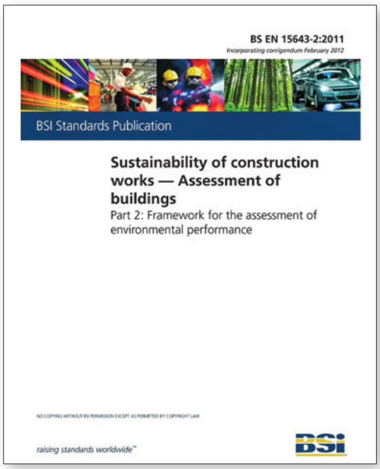
The New Zealand LCA society (LCANZ) has many useful LCA resources (definitions, case studies, Frequently Asked Questions), including references within a NZ context, on their website (see References and Further Reading).

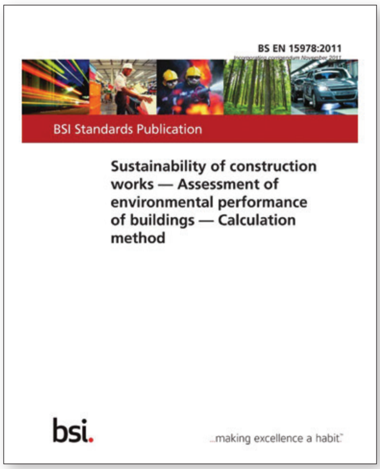
B2 LIFE CYCLE ASSESSMENT AS USED IN CONSTRUCTION

Life Cycle Assessment is used in the construction industry for construction materials, products and even entire buildings. In addition to ISO 14040 and 14044, other standards, specific for these applications have been developed, the most widely adopted being those developed in Europe by the Technical Committee (TC), CEN/TC350.

This committee was charged with developing standards for the sustainability assessment of buildings. There are 3 key standards relating to environmental impacts of construction:

- EN 15643-2: setting the overarching framework for the environmental performance of the built environment on a local, regional and global level,
- EN 15978 at the building level, setting the calculation methods, when assessing the environmental performance of buildings,
- EN 15804 is the standard at the 'product level', setting the rules for evaluating the environmental impact of construction products.

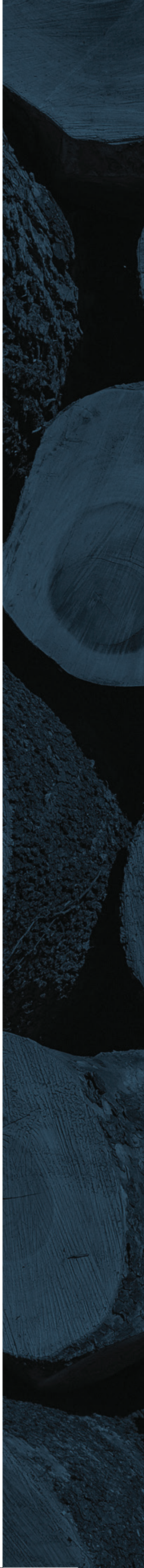




They essentially show how to make LCA applicable to the environmental sustainability of construction.

Standard EN 15804 sets out the methodology and procedures for LCA specifically for construction products, known as Product Category Rules, or PCRs. EN 16485 is the European standard covering the product category rules for wood and wood based products used in construction.

Although these are European standards, they are used around the world and are all available from Standards New Zealand.



APPENDIX C: CARBON STORAGE IN NEW ZEALAND FORESTS

C1 CARBON SEQUESTERED IN FORESTS

We have seen previously how trees growing in forests absorb Carbon Dioxide (CO_2) from the atmosphere through photosynthesis and store the Carbon in wood, and about half the weight of dry wood is Carbon. In a living forest, additional Carbon is stored in leaves and branches, decaying biomass and in the soil.

The amount of Carbon sequestered in a mature plantation forest is about 270 tonnes per hectare (equivalent to 1000 tonnes of CO_2 per hectare). This amount of stored Carbon is roughly the same on average in a mature native forest or in a mature plantation. There is much variability depending on species, age and location.

The Carbon balance of a mature native forest is in a long-term steady state, with Carbon losses from dead and dying plants balanced by Carbon gains through photosynthesis in the leaves. The climate benefit of mature native forests is the large amount of sequestered Carbon stored in the woody biomass. Most of this Carbon would be emitted if the forest was burned or converted to another land use.

If an exotic forest is managed for wood production, typically with harvesting and replanting about every 30 years, the long-term average amount of Carbon stored in the forest is about half of that in a mature forest (equivalent to about 500 tonnes of CO_2 per hectare).

C2 CARBON CREDITS FOR FORESTRY

Landowners who plant new forests on unforested land can claim Carbon credits under the Emissions Trading Scheme, to recognise the increasing pool of sequestered Carbon which will be stored in the forest on their land. This so called “Carbon forestry” must be done on pasture, shrubland or in other areas where there was no existing forest in 1990. Under new accounting rules owners will claim credits for harvested plantation forests up to the long-term average Carbon storage potential for the forest, which equates to about the first 15 years of growth. There will be no credits or liabilities beyond that time, so it is a ‘one-off’ benefit. Owners of forests that existed before 1990 are not eligible to earn credits, and mature unharvested forests will reach a stage where they do not generate further credits because the pool of Carbon is in a steady state, not increasing over time.

C3 FORESTRY AS AN OFFSET FOR FOSSIL FUEL EMISSIONS

For forests to be used to offset fossil fuel emissions, they must be new forests on unforested land, creating a new pool of sequestered Carbon in the woody biomass.

When consumers of air travel or other polluting activities purchase Carbon offsets, the money is most often used to buy Carbon credits from the owners of new or growing forests. Buying Carbon offsets does not reduce the amount of CO_2 in the atmosphere; it only helps to prevent any increase. Forestry is not a long-term solution to continued fossil fuel use, because the availability of more and more land will become difficult, and landowners must make commitments for the land to remain forested in perpetuity.

If land planted for Carbon credits is ever de-forested, the landowner will be required to surrender the credits by buying replacement credits which could cost a lot more than the initial payment, unless an equivalent area of new forest is planted elsewhere.

C4 ONE BILLION TREES PROGRAMME

The New Zealand government launched the One Billion Trees programme in 2018 to encourage planting of that many trees over 10 years for a variety of benefits, including Carbon sequestration. The Carbon which will be sequestered by the One Billion Trees programme is not nearly enough to offset New Zealand’s increasing emissions from fossil fuel. There is much debate whether to plant permanent native forests or to plant managed exotic forests for wood production.
The best solution depends on the objectives of the programme.

C4.1 Native Forests

Growers of native forests on unforested land can claim payment for Carbon credits until the forest matures. No further Carbon credits are payable after the forest reaches maturity but this may take hundreds of years, and the land must remain forested for ever.

A big disadvantage of native forests for Carbon sequestration is that most native tree species grow much more slowly than exotic plantations, so that a much longer time is necessary to reap the Carbon benefits both in terms of income from Carbon credits and offsetting emissions.

C4.2 Production Forests

The big Carbon benefit of fast-growing exotic forests is the speed with which the trees sequester Carbon. The average rate is over 10 tonnes of Carbon (equivalent to over 30 tonnes of CO_2) per hectare per year. This is several times faster than Carbon sequestration in native forests. The disadvantage of exotic forests is that most are harvested and replanted on a regular basis for wood production. The average long-term pool of sequestered Carbon in the harvested forest is only about half of that in a mature stand. However this ignores the impact of wood products, discussed below.

C4.3 Permanent Exotic Forests

A controversial compromise between slow growing native forests and fast-growing production forests is to plant fast growing exotic species and transition them to permanent native forests over time. This approach would maximise sequestration, allowing the landowner to receive Carbon credits at the higher rate until the forest matures, with no reduction for averaging. Large permanent forests of exotic species may cause concern in many quarters, but some unharvested exotic forests will eventually revert to native forest, with the resulting long-term benefits.

C5 CARBON CREDITS FOR PRODUCTION FORESTS

Figure C1 (from Young and Simmons, 2016) is a sketch showing the amount of Carbon stored in a typical New Zealand production forest managed on a 30 year rotation. The green triangles show a steady increase in Carbon sequestered as the forest stand grows, reaching 1000 tonnes of CO_2 equivalent in 30 years. The stored Carbon drops to zero when the stand is harvested and slowly increases again after replanting on a 30 year repetitive cycle.

The actual amount of Carbon stock in a forest depends on many factors including the tree species, and the location in New Zealand. Te Uru Rakau (Forestry New Zealand) has Carbon look-up tables for forestry in the Emissions Trading Scheme (ETS)(Te Uru Rakau, 2018), showing pre-calculated values of Carbon stocks (tonnes of CO_2 equivalent per hectare) for different locations and species. The values in Figures C1 and C2 are representative of typical forests, but there is a lot of variation between sites, ages and species.

C5.1 Harvest Residues

Sequestered Carbon is not released to the atmosphere immediately after the forest is harvested because it remains in wood. Referring to Figure C1, the brown areas in the valleys between the green triangles are estimates of the Carbon remaining on site in harvest residues. These reduce slowly as the waste wood and roots rot away over the next 30 years, and the Carbon is released to the atmosphere.

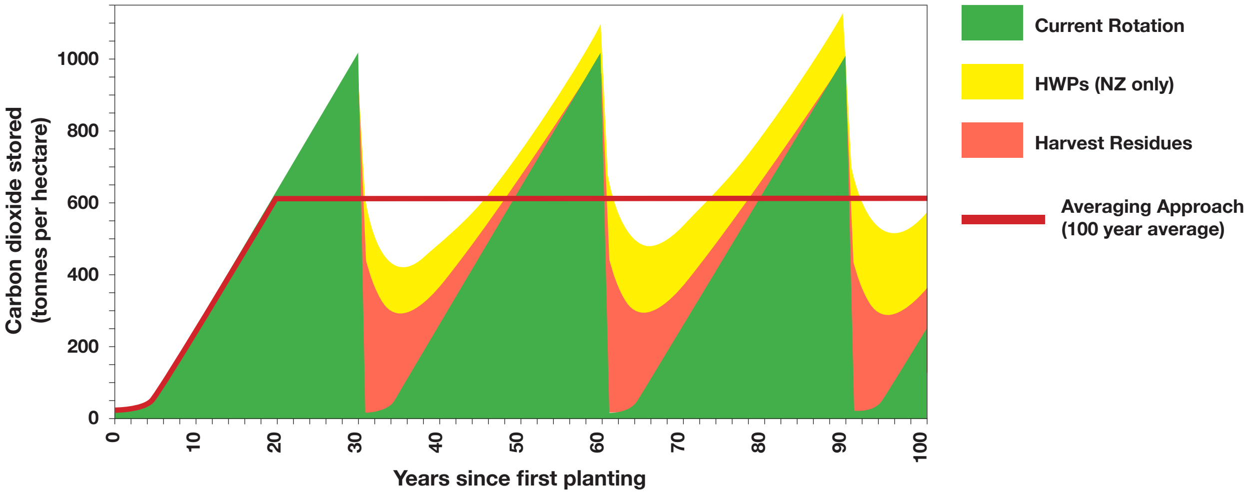


Figure C1: Carbon stored in a production forest managed on a 30 year rotation.

C5.2 Harvested Wood Products (HWPs)

The yellow areas in Figure C1 show an estimate of the Carbon remaining in long-life harvested wood products (HWPs).

The height of the yellow area is much less than the height of the green triangles, because many logs are exported to other countries, only about half of the wood in a log is converted to sawn timber, and some wood products do not meet the definition of HWPs. Some wood residues are utilised as wood chips for panel products and as Carbon-neutral fuel for energy production.

The continually increasing height of the yellow tips during the 30 year cycles represents the increasing volume of Carbon stored in HWPs. The assumptions for calculating this volume of HWPs are not known, but the volume could be much larger if there is a big increase in the number of timber buildings in New Zealand.

C5.3 Averaging

Following proposed changes to the New Zealand ETS, the red line in Figure C1 shows the 100-year average amount of Carbon sequestered in the forests and harvest residues. After a steady climb for the first 15 years, the line is horizontal, showing that the average amount of stored Carbon is constant.

If the owner of this new forest claims Carbon credits, the credits would only be payable for the first 15 years. No more credits can be claimed beyond that date, and all the credits have to be repaid if the forest is cut down and converted to non-forestry land use.

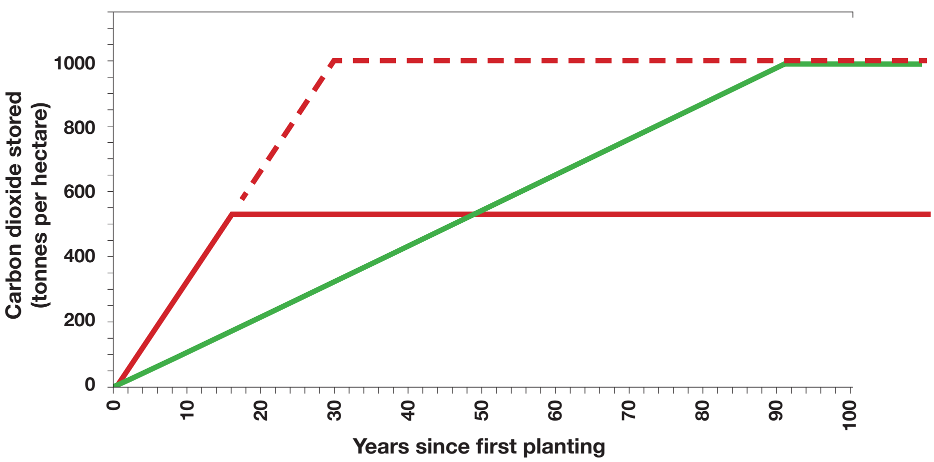


Figure C2: Carbon stored in permanent forests

C5.4 Comparison with Permanent Forests

Figure C2 is a simplified version of Figure C1. The solid red line A is the same as the red line in Figure 1, showing the long-term average amount of Carbon stored in the forest, being about 500 tonnes of CO_2 per hectare.

The dotted red line B shows the amount of Carbon stored after 30 years if the forest is not harvested. In this case the forest owner would be able to claim Carbon credits at the same rate for 30 years, up to a total of 1000 tonnes of CO_2 per hectare. Many exotic forests will continue to grow and sequester Carbon for much longer, up to 60 years or more.

The green line C in Figure C2 shows the Carbon sequestration for a native forest which grows at only one third the rate of the exotic forest. In this case the forest owner would be able to claim for the same total of 1000 tonnes of CO_2 per hectare, but at a much slower rate over a period of 90 years. Most native forests will grow even more slowly than this.

C5.5 Size and Sustainability of New Zealand Forests

Of the 1.73 million hectares of commercial forest in New Zealand, over 1.1 million hectares, around 66%, are owned and managed by companies which have achieved Forestry Stewardship Council (FSC) certification. This is an international scheme which demonstrates the sustainability of wood products from forests, and meets the criteria for assuming the Carbon neutrality of the biogenic Carbon in timber products as stated in EN 16485.

The net area of forest cover in New Zealand is increasing, in part due to the 1 Billion Trees programme. In 2018, afforestation was 9,100 hectares, and replanting totalled 48,000 hectares (FOA facts and figures 2018-2019).

The majority of structural wood products made and sold in New Zealand or exported abroad, is FSC certified. (A small proportion of New Zealand forests are certified with another certification scheme, the Programme for the Endorsement of Forest Certification, PEFC). The demand for the certified timber is growing, driven by international standards and other schemes for assessing sustainability, such as GreenStar. The remaining 30% of forests in New Zealand that are not FSC or PEFC certified are mostly small holder forests, less than 2000 hectares in size. Certification involves aspects of economic and social sustainability, as well as other environmental sustainability issues besides Carbon, including pay and work conditions for employees, and the cost of the administrative effort is often not justified for these small holders.

APPENDIX D: Chemical Treatments and Adhesives in Timber Products

This Wood Design Guide has focused on Carbon emissions as a metric for the environmental performance of timber used in construction, given that reducing greenhouse gas emissions is imperative in combating global climate change, the largest environmental challenge we face. The use of chemicals as adhesives and treatments for timber products have an additional global warming potential impact, alongside other environmental impacts, which are also discussed here. A detailed exploration of all aspects of timber adhesives and treatments can be found in other Wood Design guides.

D1 ENVIRONMENTAL IMPACTS OF TREATMENTS

The New Zealand Building Code clause B2 sets out performance requirements for building components in terms of their durability, namely that the individual components will satisfy all other objectives of the Building Code throughout the design life of the building, or in the event of their degradation, they are easily replaceable.

With timber construction materials, these requirements are typically met by using a naturally durable species, or using chemical treatment. Radiata pine, the most widely used timber species in New Zealand, has a particularly permeable cell structure, limiting its natural durability but making it very easy to treat. Chemical preservatives are impregnated into the timber, to prevent rot, fungal and insect attack and other types of degradation that may otherwise occur due to the environment the timber is exposed to. Treated timber is used in a wide range of applications in addition to building structures, including landscaping and agricultural applications such as earth retaining structures and fencing.

The most common chemicals used for timber treatments are:

- Boron compounds: Boron is a water-based preservative frequently used for framing timber.
- LOSP (light organic solvent preservative): a solvent such as white spirit is used to impregnate the timber with chemical insecticides and fungicides such as tributyl tin oxide (TBTO) in a vacuum process. The solvent evaporates from the timber after treatment.
- CCA compounds (Copper Chromium Arsenic): the Copper and Arsenic protect against fungal decay and wood boring insects, Chromium is used to fix the preservative to the cell structure in the wood. Leaching of the chemicals from the wood is minimal, but it is not typically used where it may come into contact with drinking water.

Other forms of treatment such as copper azole-base (CuAz) and alkaline or ammoniacal copper quaternary-based (ACQ) contain higher levels of copper than CCA treatment but are therefore more corrosive to metals, so care is required when selecting fixings into wood treated this way.

Often treatments types are referred to according to a Hazard class (H1.1, H1.2, H3.1 etc) which can cause confusion. It should be noted that although the treatment specification is linked to a Hazard class, the hazard class defines a level of performance that can be met by a variety of treatment specifications, and the same treatment type can be used to achieve different Hazard Class performance levels.

Humans and the environment can be put at risk if exposed to the chemicals used for timber treatment at sufficient levels. The environmental impacts of timber treatments used in construction products can be evaluated by consulting their EPDs. Some EPDs for timber products isolate the impact of the treatment so they can be compared with the impact of the production of the timber product itself.

Figure D1 shows the global warming potential results from the NZ WPMA EPD for Sawn kiln dried timber with various preservative treatments. The values show the embodied Carbon for the production stage, A1-A3 (cradle to gate): note the CO2 emitted has been separated out into biogenic Carbon, that is emissions from burning biomass fuels, typically timber offcuts used for the kiln drying process in this situation; and fossil-derived carbon emissions, from burning fossil fuels. Biogenic Carbon emissions are considered to be Carbon neutral, as they are returning CO_2 to the atmosphere that was only recently removed through the process of photosynthesis, so there is no change to atmospheric CO_2 over the relatively short timescale of the life of a tree. In comparison, emissions from fossil fuels represent a permanent addition of CO_2 to the atmosphere, contributing to a net increase in CO_2 levels and an increase in the greenhouse effect.

It can be seen that the impact of treatment on the cradle-to-gate Carbon footprint of timber construction products is minimal, and that even for the treatment with the greatest impact, a H3.1 level of LOSP treatment, the GWP impacts of the treatment and all the other processing at this life cycle stage are still outweighed by the impact of the sequestered Carbon stored in the timber itself.

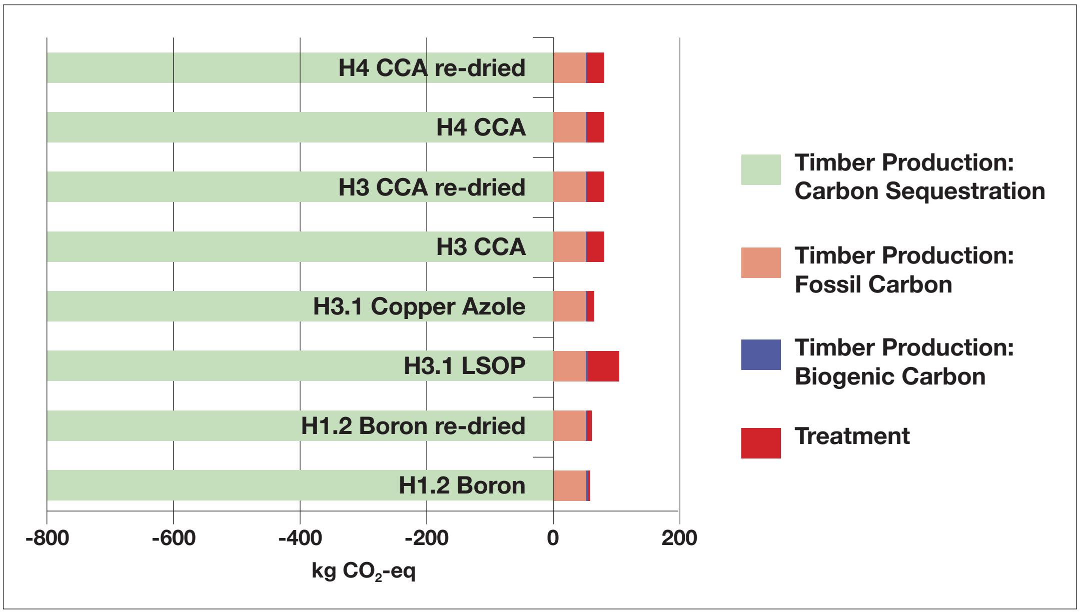


Figure D1: Global Warming Potential (GWP) for Module A1-3 (cradle-to-gate) of 1m³ sawn kiln dried timber, various treatment methods (WPMA EPD).

EPDs contain the results of LCA across a number of environmental impact categories, of which global warming potential, kg CO_2-eq emissions, or Carbon footprint, is just one. Impact categories where timber treatment is most significant are ozone depletion potential, ozone creation potential and abiotic depletion potential and these are shown in Figures D2-D4:

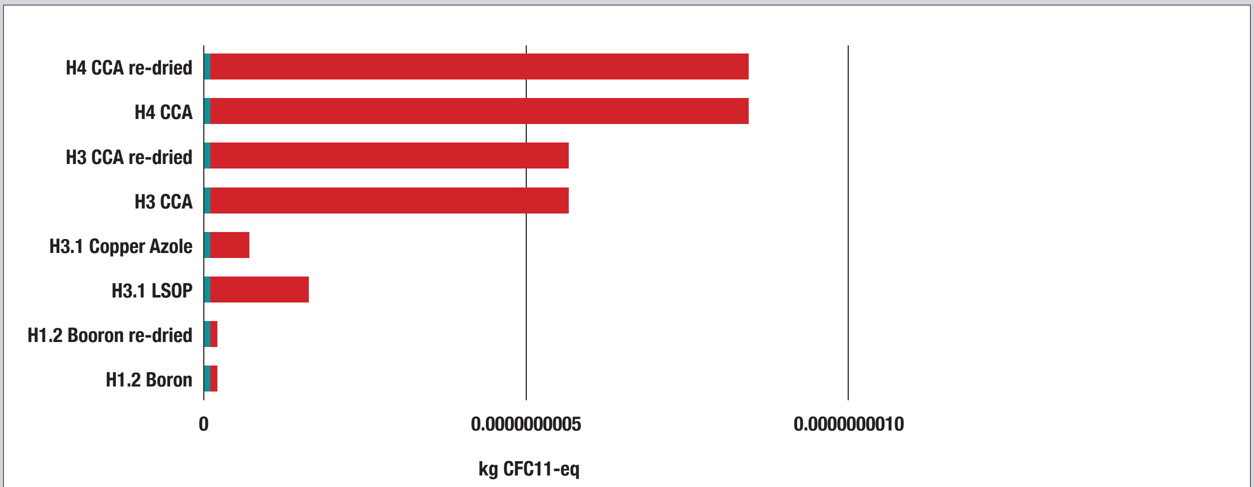


Figure D2: Abiotic Depletion Potential-mineral resource elements (ADPE) for Module A1-3 (cradle-to-gate) of 1m³ sawn kiln dried timber, various treatment methods (WPMA EPD).

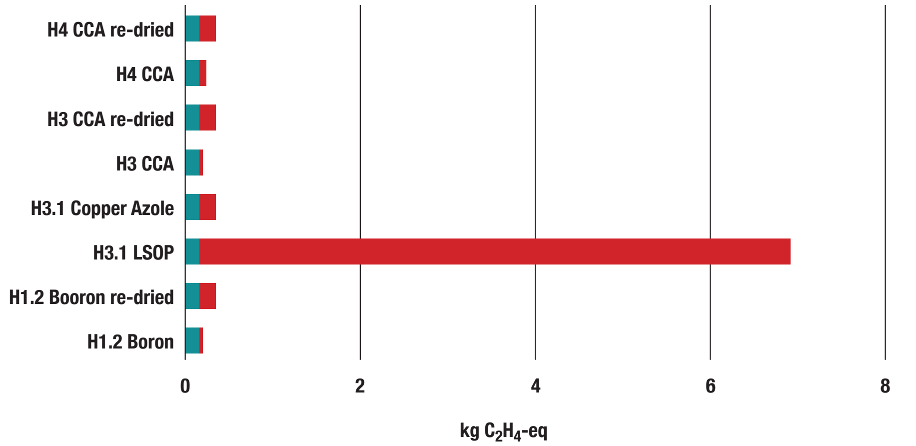


Figure D3: Photochemical Ozone Creation Potential (POCP) for Module A1-3 (cradle-to-gate) of 1m³ sawn kiln dried timber, various treatment methods (WPMA EPD)

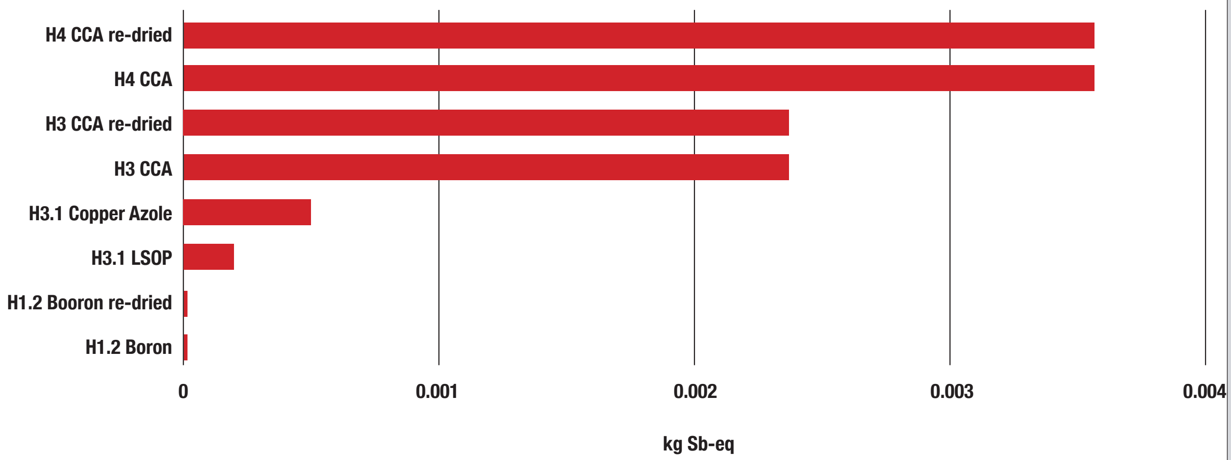


Figure D4: Abiotic Depletion Potential-mineral resource elements (ADPE) for Module A1-3 (cradle-to-gate) of 1m³ sawn kiln dried timber, various treatment methods (WPMA EPD).

For each of these impact categories, the absolute value of the impact should be compared with the impact in that category from other construction materials. For, CCA treatment greatly increases the Ozone Depletion Potential of timber, but data from the Allied Concrete EPD for readymix concrete made in New Zealand shows the ODP of 30MPa concrete is 10,000 times greater than the equivalent amount of H4 CCA treated timber to achieve the same structural performance.

As previously discussed, the end-of-life impacts of timber construction products require careful consideration when evaluating their environmental impact across their life cycle. The end-of-life options for timber are reduced for treated timber in New Zealand, as most treatments would cause harmful emissions if they were burned, and so this is not permitted in New Zealand. This means treated timber must be landfilled if it cannot be recycled, which although we have seen in Section 3.3.7, may not have a detrimental effect on the whole life Carbon impacts, it will create pressure on waste processing facilities and is generally not acceptable as a sustainable solution.

There has been considerable research effort into the environmental impact of treated timber waste in New Zealand, and options to reduce it in future. The treated timber waste minimisation project funded by Environment Canterbury and the Review of end-of-life options for structural timber buildings, from the Structural Timber Innovation Company (STIC) research and development company at the University of Canterbury are useful sources for further detail on this subject (see references).

D.2 ENVIRONMENTAL IMPACTS OF ADHESIVES

Engineered timber products used in structural applications (sometimes called Engineered Wood Products or EWPs), such as glue-laminated timber, laminated veneer lumber, cross laminated timber and plywood are formed by using layers of timber and bonding them together with adhesives. Although this increases their carbon footprint, by introducing a fabrication process, the main driver for doing so is to improve the level and consistency of structural performance. A section of timber is only as strong as its weakest point, usually a knot, and as a natural product, there is a large variation in material properties. By laminating multiple layers together, this variation can be reduced, increasing characteristic strengths and overcoming limitations on product dimensions due to tree trunk sizes.

EWPs can be used in wider structural applications than sawn timber, and although they are still a small fraction of the market for timber used in construction, their use is increasing.

Adhesives used for EWPs typically come from one of the following types:

- Phenol-based adhesives e.g. phenol-formaldehyde (PF), phenol-resorcinol-formaldehyde (PRF). These are mainly used in structural plywood and LVL production, i.e. gluing veneer. Phenol adhesives have two or three components and cure at high temperatures.
- MUF adhesives, or two-component melamine-urea-formaldehyde adhesives. These are used in the production of many structural wood products, including glulam. They also cure at high temperatures.
- One-component PUR adhesives, otherwise known as polyurethane adhesives, are used in the production of glulam and CLT and can also be used to bond layers of LVL sheets. Polyurethane wood adhesives cure when exposed to moisture at room temperature. Polyurethane adhesives are prepared using a polyol and isocyanate reaction, similar ingredients are also used elsewhere in everyday environments, including furniture upholstery foams and sports shoes.
- Emulsion polymer isocyanate adhesives (EPI) are made from dispersion adhesives and isocyanate cures. The adhesive hardens by drying at room temperature. EPI adhesives are more commonly used outside of Europe in the production of small-dimension finger jointing, glulam and laminated logs.

Figure D5 shows the adhesives used for timber construction products available in New Zealand.

LVL (Nelson Pine, Juken NZ and Futurebuild?	**Phenol Formaldehyde resin. The resin makes up around 10% of the mass of the final product.**
CLT made in Australia/NZ (XLam, produced in Nelson then Australia since 2019, and Red Stag, produced in Rotorua?	**PUR adhesives, typically around 2% of the mass of the final product.**
CLT imported from European suppliers	**MUF, PUR and EPI adhesives, or a combination mixed together, 0.75-2% content by mass of the final product.**
Glulam (e.g. Techlam, Timberlab, Prolam	**MUF is the most widely used adhesive for glulam used in internal environments, but PUR, EPI and PRF can also be used. For external applications only PF, PRF or PUR adhesives are used. Typical quantities are similar to CLT, around 2% by mass.**
Structural plywood (e.g. Ecoply, Tuffply)	**Phenol formaldehyde resin is used by Ecoply, the most widely used structural plywood in NZ, and is typical for other plywood manufacturers. MUF adhesives may also be used. Typical quantities are 3-5% by mass.**

FigureD5: Adhesives commonly used in timber products in New Zealand.

Concerns about the potential environmental impacts of adhesives in EWPs typically include the increased Carbon footprint, toxicity, and implications on the end-of-life options for the product.

The Carbon footprint of adhesives must be included in the LCA for an EWP, and so is reported in the Environmental Product Declarations (EPD). The impact of the adhesives are generally are not separated out from forestry and timber processing activities in an EPD. However it can be seen from comparing the products in Figure 19 (which have a wide range of adhesive content) that the impact of adhesives in EWP are generally not significant when compared to the Carbon sequestered in the timber. The difference in the embodied Carbon cradle-to-gate values for surfaced kiln dried timber and glulam reported in the WPMA EPD is around 8%, and this difference will also include the additional processes involved in making the engineered product. The proportion of adhesive used in EWP is generally small, with the highest level being around 10% in LVL.

Toxicity concerns around EWP generally focus on formaldehyde adhesives, used in LVL, plywood and some Glulam products. Formaldehyde present in the air at levels exceeding 0.1 parts per million (ppm) can cause health issues, such as coughing and skin irritation, and its long term effects are not well known. It is a naturally occurring chemical, made in small amounts by most living organisms, including humans, and trees. It follows that all wood products contain small amounts of formaldehyde, irrespective of any adhesive used. Historically there have been concerns about formaldehyde emissions from wood panel products, but manufacturers now ensure that products meet modern stringent international formaldehyde emission standards. AS/NZS 2269.0:2012, the New Zealand standard for structural plywood specification has updated formaldehyde emissions classes, Ex, and now includes a new 'Super E0' class, reflecting the marketplace expectations for lower formaldehyde emissions. All structural plywood used in New Zealand meets the E0 class, where formaldehyde emissions <0.5mg/litre, products meeting the new 'Super E0' have emissions <0.3mg/litre, similar to natural wood. These products meet standards that require emissions levels in buildings to be below 0.2 ppm, typical for internal environments.

It has been shown that the use of some preservative treatments may preclude the timber from being burned at end-of-life, as the chemical treatment would result in harmful emissions. However the same is generally not true for all adhesives in EWP. Information from TRADA, the UK timber industry research and development association, states that the glues used in CLT and particleboard materials makes them suitable as biomass fuels, and EPDs for EWP usually have incineration as an end-of-life scenario. Any harmful environmental impacts from the combustion of the adhesives will be captured in the results of Module C3 under the incineration or energy recovery scenario, and it can be seen in the WPMA EPD that these are small for New Zealand EWP. However, although EWP are relatively new in construction (and so there are few buildings that use it that have reached their end-of-life), it is expected that their inherent value will be too high to make incineration a sensible option. It is more likely that EWP will be reused or recycled, 'cascaded' down to form other wood products.

SCION is researching the properties of natural adhesives, to be used as a substitute for petrochemical based adhesives. Ligate is a water soluble biobased product that is derived from lignin, a byproduct of pulp and paper manufacture, and its used has been demonstrated in plywood and MDF panels. As of 2019, its use is being evaluated in trials with commercial partners.

ABOUT THE AUTHOR

Katie Symons is a structural engineer with a strong interest in the environmental sustainability of construction materials. She studied engineering at Cambridge University and has worked in structural design for small and large consultancies in the UK and New Zealand for 15 years. She is a Chartered Structural Engineer and has designed and delivered a number of timber, steel and concrete buildings. She is the author of numerous publications on sustainable construction and has also undertaken academic research into developing embodied Carbon assessment tools. She is based in Christchurch.

SUMMARY

1. The use of wood in construction can reduce a building' environmental impact with respect to climate change in two ways:
   - By substituting for materials with a higher embodied Carbon (the substitution effect),
   - By storing Carbon that has been sequestered (by trees), effectively 'locking up' Carbon for the long term.
2. The Carbon footprint of a building includes Operational and Embodied Carbon impacts. As buildings become more energy efficient, Embodied Carbon impacts are becoming more important.
3. A full Carbon footprint of timber products includes all stages of the building's whole life cycle, which includes 'cradle-to-site' processes, activities during the building's operation, and end-of-life impacts.
4. Although end-of-life impacts for timber construction products are hard to assess because of assumptions that need to be made, there is increasing certainty on the amount of Carbon Dioxide that is returned to the atmosphere for each scenario, particularly for disposal in landfill, which is not as much as previously thought.
5. Life Cycle Assessment (LCA) is becoming more mainstream and accessible, with life cycle data published in Environmental Product Declarations (EPDs) becoming more widely available.
6. The low Carbon footprint of timber construction products will become increasingly recognised in sustainable building rating tools and indicators, as they move from only addressing operational emissions to also focussing on embodied Carbon.
7. Most timber products made from New Zealand forest can be certified as sustainable, and currently the amount of forest cover in New Zealand is growing.
8. Chemical treatment and adhesives used in timber construction products do add to the environmental impacts of these products, but when compared to alternative materials, they are often negligible.
9. Timber buildings can play a part in meeting New Zealand's greenhouse gas reduction targets, but afforestation should not be used as a substitute for reducing emissions from the use of fossil fuels.

GLOSSARY

Many of the terms here do not have established standardised definitions, and have different meanings in different organisations or countries. The definitions below are the meaning of the terms as used in this guide.

EMBODIED CARBON

In the context of construction materials or products, Embodied Carbon considers the amount of greenhouse gas emissions that are released throughout a production supply chain to produce a material or product. It is often measured with the boundaries of cradle to gate, cradle to site, or cradle to grave. It considers all extraction, transport, processing and fabrication activities of a material or product.

In the context of a building, Embodied Carbon is the sum of the Embodied Carbon of all the constituent materials or products within the building.

OPERATIONAL CARBON

In the context of a building, Operational Carbon is the amount of greenhouse gas emissions that are released as a result of the operation of the building, i.e. from the energy used to light, heat and cool the building, as well as provide other services such as hot water. It excludes any emissions arising from the production supply chain to produce the materials and products that make up the fabric of the building.

CARBON FOOTPRINT

A Carbon footprint is a measure of the amount of greenhouse gas emissions and removals across the boundaries of a Life Cycle Assessment (LCA) study, reported in the impact category of climate change or Global Warming Potential (GWP). A Carbon footprint is often measured in the units of kg or tonnes of CO_2-eq. A true Carbon footprint starts at the cradle and measures the release of greenhouse gas emissions throughout a supply chain or life-cycle.

CARBON DIOXIDE (CO_2) EQUIVALENT

Denoted as CO_2-eq, but can be shortened to CO_2-e, ECO_2 etc. The CO_2-eq of a specific amount of a greenhouse gas is calculated as the mass of a given greenhouse gas multiplied by its global warming potential. ISO 14067:2018 defines a CO_2 equivalent unit as a "unit for comparing the radiative forcing of a greenhouse gas to that of Carbon Dioxide."

LIFE CYCLE ASSESSMENT/ANALYSIS

Life Cycle Assessment, also known as Life Cycle Analysis (LCA), considers a full basket of environmental impact categories, beyond just Carbon. For example it can produce results for toxicity, eutrophication, acidification, water depletion, resource depletion and others. LCA can be a powerful decision support tool, but requires a higher level of expertise than an embodied carbon assessment or Carbon footprint.

ENVIRONMENTAL PRODUCT DECLARATION

An Environmental Product Declaration (EPD) is an independently verified public declaration of environmental performance of a product for all or parts of the product's life cycle. EPDs provide an internationally recognised format for declaring the environmental performance of a product, based on LCA. They are generally voluntary (with some exceptions) and may be produced for specific materials and products or an average of the same or similar products within a sector (for example, at a trade association level).

CARBON SEQUESTRATION

When a tree grows it absorbs Carbon Dioxide (CO_2) from the atmosphere (through photosynthesis) and stores the Carbon within the tree. This is a form of sequestration. The Carbon that sequestered by the tree is stored in the wood and resulting timber products. This is taken as biogenic Carbon storage in an embodied Carbon assessment. Note that timber products do no sequester Carbon, they store Carbon that has been sequestered by the tree from which is was made. It is important to appreciate that at the end-of-life of timber, the stored Carbon may be released back into the atmosphere, depending on the scenario assumed for the end-of-life. If including sequestered Carbon sequestration in an LCA study, then it's important to take care in modelling the results and to appreciate the end-of-life scenario.

BIOGENIC CARBON

Biogenic Carbon is the term used to describe CO_2 emissions related to the natural Carbon cycle, as well as those resulting from the combustion, harvest, digestion, fermentation, decomposition or processing of biologically based materials. In the context of timber used in construction, the CO_2 emitted as a result of the combustion of biological material, such as wood, is an example of biogenic CO_2 emissions. Conversely, when CO_2 is removed from the atmosphere by photosynthesis to produce biomass in trees, the resulting Carbon stored in the wood is termed biogenic Carbon.

ENGINEERED TIMBER

Engineered timber, also called mass wood or mass timber, includes a range of derivative wood products which are manufactured by binding or fixing the strands, particles, fibres, or veneers or boards of wood, together with adhesives, or other methods of fixation to form a composite material. Engineered timber products make more efficient use of wood as they can be made from small pieces of wood, with fewer defects than natural timber products. They can be designed and manufactured to maximize the natural strength and stiffness characteristics of wood, making them very stable and offer greater structural strength than the natural wood material from which they are manufactured.

CRADLE-TO-GATE

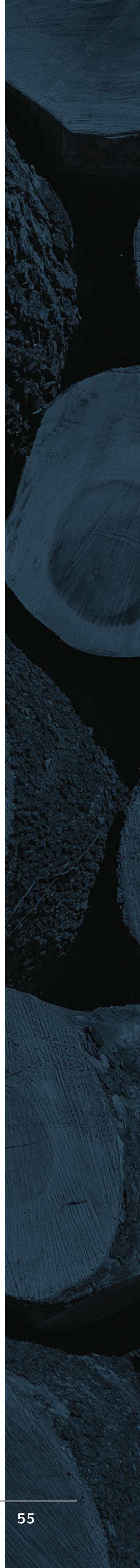
Cradle-to-Gate is a boundary condition associated with embodied Carbon, Carbon footprint and LCA studies. A study to these boundaries considers all activities starting with the extraction of materials from the earth (the cradle), their transportation, refining, processing and fabrication activities until the material or product is ready to leave the factory gate. (Modules A1-A3 in the EN 15804 framework).

CRADLE-TO-SITE

Cradle-to-site is a boundary condition associated with embodied Carbon, Carbon footprint and LCA studies. A study to these boundaries includes the cradle to gate results and the transportation of the material or product to its site of use (Modules A1-A5 in the EN 15804 framework).

CRADLE-TO-GRAVE

Cradle-to-grave is a boundary condition associated with embodied Carbon, Carbon footprint and LCA studies. A study to these boundaries includes the cradle to site results but also includes the greenhouse gas emissions associated with the in use of the material or product (maintenance) and the end-of-life (disposal, reuse, recycling) (Modules A, B and C in the EN 15804 framework).



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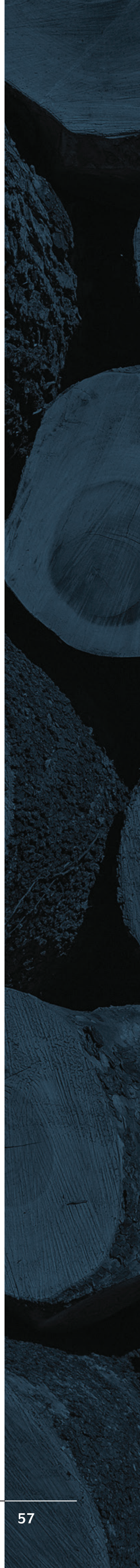

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