Study Report SR418 [2020]

New Zealand whole-building whole-of-life framework: LCAQuick v3.4 – a tool to help designers understand how to evaluate building environmental performance

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Preface

In April 2013, BRANZ commenced research into development of a New Zealand whole-building whole-of-life framework. The purpose of the framework was to establish a level playing field for evaluation and reporting of the environmental impacts of building designs in comparison with an appropriate reference building, based on life cycle assessment (LCA).

As part of this research, an Excel-based tool was developed called LCAQuick, which calculates potential environmental impacts of building designs using the framework. Initial focus was on offices.

LCAQuick was launched at BRANZ seminars in Auckland, Wellington and Christchurch in 2016. For this research project, it has now been updated and expanded to include residential building typologies.

This report summarises the work that has been undertaken.

Previously published framework research reports are available on the BRANZ website at www.branzfind.co.nz and include the following:

- Berg et al., 2016
- Dowdell et al., 2016.
- Dowdell and Berg, 2016.
- Dowdell, 2014.
- Dowdell, 2013b.
- Dowdell, 2013a.
- Dowdell, 2012b.
- Dowdell, 2012a.

Other framework resources available for use:

- LCAQuick, which can be downloaded for free from the BRANZ website at www.branz.co.nz/lcaquick.
- BRANZ CO_2NSTRUCT – a database of embodied greenhouse gas and embodied energy for a selection of construction materials and products is available for download at www.branz.co.nz/co2nstruct.
- Supporting data developed to inform the LCA of New Zealand buildings is available at www.branz.co.nz/buildinglca (and select “Data”).
- LCAQuick training and other videos are available on the BRANZ YouTube media channel at www.youtube.com/playlist?list=PLQeYTsvZ7o2yOIYdXCGYD27n6PCowu_te

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Note

This report provides the background to LCAQuick v3.4,[1] including the reference residential buildings that are embedded in the tool. This report supersedes parts of the BRANZ Study Report SR350 (Berg et al., 2016), specifically, Appendix D and E of that report.

This report is intended for those that are interested to understand in more detail how the reference residential buildings embedded in LCAQuick have been modelled, including assumptions and supporting data.

[1] Version 3.3 of LCAQuick was made available for download from the BRANZ website (www.branz.co.nz/lcaquick) in September 2019. Version 3.4 was made available in February 2020. The main differences between v3.3 and v3.4 of LCAQuick are covered in sections 6.1 and 6.5.

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Abstract

Previous research undertaken by BRANZ with industry partners resulted in the development of a New Zealand whole-building whole-of-life framework (available at www.branz.co.nz/buildinglca), which includes information and data to support application of life cycle assessment for evaluation of building designs. This research additionally resulted in the development of a free Excel-based design-support tool called LCAQuick with the aim of using the tool to help design teams and their clients better understand what LCA is, how to interpret it and how to incorporate it into workflows. The first version of LCAQuick was focused on office buildings and contained a reference library of commercial office and commercial mixed buildings that could be used as comparators by design teams.

The original research has now been expanded to include residential building typologies. This has necessitated expanding the supporting data embedded in LCAQuick and adding functionality borne out of practical application of the first version of LCAQuick by design teams. LCAQuick has also been consolidated into one tool, having originally been released as multiple versions.

This research has additionally included modelling 12 reference residential buildings, which provide a library embedded in LCAQuick for comparative purposes during design. This reference library includes stand-alone housing (single-storey and double-storey), medium-density housing and an apartment building. The stand-alone houses

include examples that are New Zealand Building Code (NZBC) compliant and "high performance" i.e. houses designed to (at least) exceed minimum requirements set out in NZBC clause H1 *Energy efficiency*.

This report sets out the underlying basis for the modelling and data behind LCAQuick v3.4 and the reference residential buildings that it contains.

Reports by the Intergovernmental Panel on Climate Change, together with increasing calls globally for climate change action, mean that tools such as LCAQuick that can be used to mitigate greenhouse gas emissions during building design are needed to help designers and their clients respond. To this end, v3.4 of LCAQuick also includes a worksheet that illustrates the climate change impact of a building design in comparison with a carbon budget. The carbon budget is a "carbon allowance" calculated for new New Zealand residential and office buildings. Achieving a design that is calculated to be within this carbon budget provides an indication that the building can be constructed and operated within natural limits (or planetary boundaries) required to meet New Zealand's Paris Agreement commitments, now enshrined in the Climate Change Response (Zero Carbon) Amendment Act 2019.

Keywords

Apartment, dwelling, LCA, LCAQuick, life cycle analysis, life cycle assessment, medium-density housing, residential, stand-alone housing.

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Acronyms and terms

AAC	autoclaved aerated concrete
ACM	aluminium composite material
APME	Association of Plastic Manufacturers in Europe
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AusLCI	A freely available life cycle inventory database of Australian products and processes developed by ALCAS. See http://alcas.asn.au/AusLCI/.
BIM	building information modelling
BMT	base metal thickness (in millimetres)
BRANZ	Building Research Association of New Zealand
building information modelling	A co-ordinated set of processes, supported by technology, that add value through the sharing of structured information for buildings and infrastructure assets (BIM Acceleration Committee, 2019).
BWA	Bitumen Waterproofing Association
CCANZ	Cement and Concrete Association of New Zealand (now Concrete NZ)
CEN	European Committee for Standardization
CLT	cross-laminated timber
CO_2NSTRUCT	A free database developed by BRANZ of embodied greenhouse gas and embodied energy for a selection of construction materials and products. The current version is version 1.0. Available at www.branz.co.nz/co2nstruct.
CR	cascade recycling
DOCf	degradable organic fraction
DPC	damp-proof course
DPM	damp-proof membrane
EcoInvent	A proprietary database of materials and processes for use in LCA, developed and maintained by The EcoInvent Centre, Switzerland. See www.ecoinvent.org.
EE	embodied energy
EECA	Energy Efficiency and Conservation Authority
embodied	Total of an environmental indicator attributed to manufacture. For example, embodied energy refers to the total of energy needed from extraction of resources through to manufacture of a final product. Similarly, embodied carbon refers to the total of greenhouse gas emissions from extraction of resources through to manufacture of a final product. May also include transport to the construction site and installation.
environmental product declaration	A voluntary declaration providing quantified environmental data using predetermined parameters and, where relevant, additional quantitative or qualitative environmental information. Also known as a Type III environmental declaration or Type III ecolabel.
EPD	environmental product declaration
EPDM	ethylene propylene diene monomer (synthetic rubber)
EPS	expanded polystyrene
ER	energy recovery
FEI	flexible equipment insulation
FWPA	Forest and Wood Products Australia Limited
GDP	gross domestic product
GFA	gross floor area – measured in square metres (m^2)
GGBS	ground granulated blast furnace slag

glulam	glued laminated timber
Green Star	The NZGBC's voluntary environmental rating tool for buildings, which assesses a building at the design and as-built phases.
gross floor area	Area measured over all the exterior walls of the building, over partitions, columns, interior structural or party walls, stair wells, lift wells, ducts, enclosed roof top structures and basement service areas. All exposed areas such as balconies, terraces, open floor areas and the like are excluded. Generally, projections beyond the outer face of the exterior walls of a building such as projecting columns, floor slabs, beams, sunshades and the like are excluded (New Zealand Institute of Quantity Surveyors, 2017).
GWP	global warming potential
HDPE	high-density polyethylene
HFC	hydrofluorocarbon
IBU	Institut Bauen und Umwelt – a German EPD programme operator for construction
ICE database	Inventory of Carbon & Energy – a database of embodied energy and carbon for a range of UK construction materials
IGU	insulating glass unit
IPCC	Intergovernmental Panel on Climate Change
ISB	intermediate service board
ISO	International Organisation for Standardization
kWh	kilowatt hour
LCA	life cycle assessment
LCAQuick	Free Excel-based early-design support tool developed by BRANZ to help architects and other professionals involved in design to better understand what LCA is, how to incorporate it into workflows and how to use LCA outputs to inform design decisions. Performs an environmental evaluation of a designed building and enables comparison to a reference New Zealand office or residential building (contained in an embedded library). The current version is version 3.4. Available at www.branz.co.nz/lcaquick.
LCI	life cycle inventory
LED	light emitting diode
LEI	light equipment insulation
life cycle assessment	Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (International Organisation for Standardization, 2006).
life cycle inventory (analysis result)	Outcome of a life cycle inventory analysis that catalogues the flows across the system boundary and provides the starting point for life cycle impact assessment (International Organisation for Standardization, 2006).
LPG	liquefied petroleum gas
LVL	laminated veneer lumber
MAF	Ministry of Agriculture and Forestry (now part of the Ministry for Primary Industries)
MBIE	Ministry of Business, Innovation and Employment (www.mbie.govt.nz)
MDF	medium-density fibreboard
MDH	medium-density housing
MfE	Ministry for the Environment (www.mfe.govt.nz)
module	Discrete part of the building life cycle that encompasses all the processes that occur. For example, modules A1, A2 and A3 cover production of materials whilst module B6 covers operational energy use in a building. The modules in the life cycle of a building are set out in EN 15978 (CEN, 2011),

	and further information is provided in BRANZ Study Report SR349 (Dowdell & Berg, 2016).
MPa	megapascal
MR	material recycling
MRF	municipal recycling facility
net lettable area	Taken as the same as net rentable/tenantable area, which is "the area available for occupation less public circulation spaces, plant and service areas and the like" (New Zealand Institute of Quantity Surveyors, 2017). Measured in square metres (m^2).
NGA	National Greenhouse Accounts
NZBC	New Zealand Building Code
NZGBC	New Zealand Green Building Council (www.nzgbc.org.nz)
OPC	ordinary Portland cement
PCR	product category rules
PE	polyethylene
PET	polyethylene terephthalate
PFA	pulverised fuel ash (fly ash)
ppm	parts per million
PR	product (code)
product category rules	Set of specific rules, requirements and guidelines for developing Type III environmental declarations (or EPDs) for one or more product categories (International Organisation for Standardization, 2006).
PV	photovoltaic
PVC	polyvinyl chloride
PVC-U	unplasticised polyvinyl chloride
RU	reuse
RoW	rest of the world (countries outside of Europe)
SCM	supplementary cementitious material
SDS	(material) safety data sheet
SHW	solar hot water
SIPs	structural insulated panels
sustainable forest management	Management of an area of indigenous forests land in a way that maintains the ability of the forest on that land to continue to provide a full range of products and amenities in perpetuity while maintaining the forest's natural values (from the New Zealand Forests Act 1949). "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems."[2]
TPO	thermoplastic olefin
XPS	extruded polystyrene
VIP	vacuum insulated panel
VOC	volatile organic compound

[2] www.pefc.org/what-we-do/our-approach/what-is-sustainable-forest-management

Executive summary

A recent Intergovernmental Panel on Climate Change (IPCC) report (Intergovernmental Panel on Climate Change, 2018), together with the Climate Change Response (Zero Carbon) Amendment Act 2019, respectively illustrate the pressing global need for and political will within New Zealand to address one of the pre-eminent issues of our time – climate change.

In 2016, BRANZ published research (Dowdell & Berg, 2016; Berg et al., 2016; Dowdell et al., 2016) to develop a New Zealand whole-building whole-of-life framework. This framework was designed to facilitate the use of building life cycle assessment as a means for New Zealand designers to quantify, evaluate and reduce the potential environmental impacts associated with their building designs.

This report summarises the continued development that has been undertaken since completion of the first phase of work in 2016, which includes:

- update and expansion of an underlying database of material/product environmental impacts
- development of reference residential building typologies to accompany the office building typologies already developed
- update of the LCAQuick tool (to v3.4), originally launched as LCAQuick – Office (v1) in 2016, with v3.3. being released in September 2019.

All resources can be found at www.branz.co.nz/buildinglca including information and supporting outputs contained in the framework as well as LCAQuick v3.4.

1. Introduction

1.1 Background

BRANZ commenced research into environmental profiling and building life cycle assessment (LCA) in 2010 to help answer questions raised by the construction industry about evaluation of environmental performance on the construction product and building scale. The initial research focused on how environmental product declarations (EPDs) underpinned by LCA can provide a robust source of information for a more consistent evaluation of the environmental performance of construction products that, in turn, can be incorporated in the assessment of New Zealand buildings across the life cycle.

Development of such a framework is important for the New Zealand construction industry:

- It provides more of a level playing field for assessment, with a focus on environmental performance of buildings across the life cycle.
- It enables evaluation of the environmental performance of buildings according to their function.
- It provides a basis for comparing building designs to better understand the sources and scale of environmental impacts across the life of a building.
- It aligns with ongoing developments in building environmental assessment according to international standards.
- It provides a holistic assessment that does not focus on single issues or specific parts of the life cycle of a building, both of which risk problem shifting from one impact to another or one stage of the life cycle to another or one medium to another.
- It provides a basis for measuring continuous improvement through recognition of innovation based on reduced environmental impacts. This can be at the construction product level through to the building level.
- It facilitates the evaluation of building environmental performance against absolute, science-based targets that consider planetary boundaries.
- It facilitates a stronger connection between supply and demand for construction products. Designers who use LCA to evaluate their building designs rely on LCA-based data for construction products, which can be provided by manufacturers and importers. By making data about their products publicly available, manufacturers and importers can ensure data for their products is accurate and representative of current production as well as demonstrating a willingness for robustness and transparency.

In February 2013, BRANZ published Study Report SR275 *Application of environmental profiling to whole building whole of life assessment – a plan for New Zealand* (Dowdell, 2013a), which set out a vision and plan for how LCA and EPDs of construction products could be integrated with LCA-based building assessment to derive quantitative impacts for buildings across the life cycle. The plan was developed with existing New Zealand initiatives, structures and organisations in mind so as not to 'reinvent wheels' and to take account of developments in international standards concerning evaluation of the environmental performance of buildings.

Following a consultation with the New Zealand construction industry, the plan provided the basis for a 3-year Building Research Levy-funded research programme to develop a New Zealand whole-building whole-of-life framework.

The aim of the framework is to provide information and resources to encourage and facilitate more consistent use of building LCA. Early work focused on offices and was divided into three research streams as follows:

- *RS1 Establish LCA-based indicators to underpin the reporting basis of the framework:* This research completed in 2014 and resulted in publication of BRANZ Study Report SR293 (Dowdell, 2014). The report sets out environmental indicators for reporting and environmental indicators highlighted for future incorporation into the framework. The report includes calculation methodologies and characterisation factors for use in calculating environmental impacts.
- RS2 Develop calculated environmental impacts for a set of reference New Zealand office buildings in order to provide an initial basis for comparison: A simple matrix for categorising office buildings was developed, and 10 New Zealand office buildings each with a gross floor area (GFA) of 1500 m^2 or more were modelled according to materials used in the structure and thermal envelope and designed energy use according to location in Auckland, Wellington and Christchurch. This work was published as BRANZ Study Report SR350 (Berg et al., 2016).
- *RS3 Develop default data for use when conducting building LCAs in the absence of specific data:* Excel datasheets were developed that provide reference data for use in building LCAs during early design, with supporting information in BRANZ Study Report SR351 (Dowdell et al., 2016). The datasheets that resulted from this work are available at www.branz.co.nz/buildinglca (and select "Data"). Whilst the information has been developed for application to early-stage design, it may also be useful for other building LCA applications.

Additionally, a tool called LCAQuick – Office was developed by BRANZ and launched in November 2016. The aim of the tool, now called LCAQuick v3.4, continues to be to provide a resource to help designers and their clients better understand how to evaluate the potential environmental impacts that may be incurred in the future because of decisions taken about the building.

1.2 Organisation of this report

This report is organised as follows:

- Section 2 covers the update and expansion of the underlying database of material/product environmental impacts.
- Section 3 covers an update of the approach to calculating environmental impacts from use of New Zealand grid electricity and emission factors for heat generation.
- Section 4 covers development of reference residential building typologies to accompany the office building typologies already developed.
- Section 5 provides information on the approach to energy simulation used for reference residential buildings.
- Section 6 provides an overview of the new features of LCAQuick v3.4 in comparison with v1 (LCAQuick – Office) originally launched in 2016.

2. Database of material/product environmental impacts

2.1 Introduction

Appendix D of BRANZ Study Report SR350 (Berg et al., 2016) provided supporting information about the first version of the material/product database that is embedded in LCAQuick. This database has now been reviewed and adjusted to develop the latest version (database v9.1), which now incorporates:

- more materials/products that are typically found in residential construction
- more product-specific data derived from EPDs provided in addition to or instead of generic data – this has been possible due to the publication of EPDs by New Zealand manufacturers or overseas suppliers.

Appendix A of this report provides information and a data quality assessment of the current version of the database of material/product environmental impacts. This covers all materials/products in database v9.1. It therefore supersedes information and the data quality assessment provided in SR350 Appendix D (Berg et al., 2016).

Some of the embodied greenhouse gas and embodied energy data collected for use in LCAQuick has additionally been published in the BRANZ CO_2NSTRUCT database, available at www.branz.co.nz/co2nstruct. Data quality for materials and products varies considerably, depending on the source of data and associated assumptions. As well as providing this environmental information, BRANZ CO_2NSTRUCT additionally provides a data quality metric.

2.2 Method for updating existing data to support calculation of environmental impacts

Data on LCA-derived environmental impacts of materials/products in the original version of the database were reviewed to assess whether more representative data were available. Improved representativeness was judged according to the following hierarchy where sources higher in the list below were considered more desirable from a data quality perspective than sources lower down the list:

- Independently verified EN 15804-compliant (CEN, 2013) EPDs for New Zealand manufactured or imported products – for example, EPDs of construction products registered with EPD Australasia.[3]
- Independently verified EN 15804-compliant EPDs for the same or similar products manufactured in other geographical locations – for example, EPDs registered on the International EPD® System[4] or IBU.[5]
- Independently verified EPDs developed to LCA standards other than EN 15804 for New Zealand manufactured or imported products.
- Independently verified EPDs developed to standards other than EN 15804 for the same or similar products manufactured in other geographical locations.

[3] Available at www.epd-australasia.com – formerly known as the Australasian EPD Programme.
[4] www.environdec.com
[5] http://ibu-epd.com/en/epd-program/published-epds/

- Modelled processes based on generic data, adapted where possible for location of manufacture – for example, including use of New Zealand grid electricity for processes in New Zealand.
- Modelled processes based on generic data in an unadapted form.

Identification of a data source that would result in a product moving up this data hierarchy triggered an update to the data.

In practice, almost all data updates related to impacts associated with manufacture of materials. This is referred to as the product stage,[6] which is subdivided into modules A1–A3 according to the building life cycle framework in the European standards EN 15978 and EN 15804.

Materials/products that already existed but for which the data on manufacturing environmental impacts have been updated are summarised in Table 1, using categories set out in Appendix A.

Table 1. Materials/products with updated data on environmental impacts.

Material type (Appendix A)	Updated material	Module					
		A1–A3	A4–A5	B2	B4	C1–C4	D
Aggregates	No updates to existing data.						
Clay (fired)	No updates to existing data.						
Concrete	The following were updated based on inclusion of Pacific Steel data (Pacific Steel, 2018) for reinforcement instead of generic data:						
	• Compressive strengths of reinforced in situ concrete including in situ concrete made with ordinary Portland cement (OPC) and in situ concrete with various proportions of cement-replacement materials – ground granulated blast furnace slag (GGBS) and pulverised fuel ash (PFA).	✓					
	• Compressive strengths of reinforced precast concrete including precast concrete made with OPC and precast concrete with various proportions of cement-replacement materials (GGBS and PFA).	✓					
	• Masonry wall, including concrete blocks, grouting and steel reinforcing.	✓					

[6] For an explanation of the breakdown of the building life cycle into stages and modules, please see section 6.3 of BRANZ Study Report SR349 (Dowdell & Berg, 2016) available for free download at www.branz.co.nz.

Material type (Appendix A)	Updated material	Module					
		A1–A3	A4–A5	B2	B4	C1–C4	D
Fibre cement	Generic data replaced with data derived from James Hardie EPD for external claddings (James Hardie, 2017).	✓					
Floor linings, excluding timber (interior)	New category, therefore no data in earlier versions.						
Glass and materials used in windows	No updates to existing data.						
Insulation	No updates to existing data.						
Membrane systems	No updates to existing data.						
Metals and metal-containing composites	Structural steel differentiated into factory painted and unpainted at factory.	✓	✓				
	Data from New Zealand Steel EPD (New Zealand Steel Limited, 2018) for Colorsteel® Endura® and Colorsteel® Maxx® with BMTs of 0.4 mm and 0.55 mm replaced generic data.	✓					
	Galvanised steel profiles and purlins and Colorsteel® products differentiated according to corrosion zone.				✓		
	Data for Pacific Steel bar replaced generic data for reinforcement.	✓					
Paint	Interior paint data from Dulux EPD (Dulux, 2017a, 2017b, 2017c) replaced generic paint data.	✓					
Plasterboard	No updates to existing data.						
Services and infrastructure	No updates to existing data.						
Timber and engineered wood	Data for glulam from FWPA EPD (Forest and Wood Products Australia Limited, 2017a) replaced Wood for Good glulam data.	✓					
	Data for MDF from Daiken EPD (Daiken New Zealand Limited & Daiken Southland Limited, 2019) added.	✓					
	Timber and engineered wood data divided into "from sustainable forest management practices" and "from unsustainable forest management practices, don't know or won't ensure from sustainable forestry".	✓					

Data published in, for example, EPDs for stages other than the product stage in the building life cycle were not necessarily updated in the database since they were often derived from scenarios that are not aligned to those previously published by BRANZ.[7]

However, the construction process stage (modules A4–A5) features wastage of construction materials/products at the construction site. Manufacture of the wasted material/product is included at this stage rather than in modules A1–A3, which just consider manufacture of materials/products that end up in the building. Therefore, an update to manufacturing data would also mean that values in modules A4–A5 are also updated.

2.3 Method for adding new materials/products

Twelve reference residential buildings have been modelled using the methodology set out in BRANZ Study Report SR350 (Berg et al., 2016) covering stand-alone (single-storey and double-storey), medium-density and apartment typologies. The stand-alone houses include both NZBC-compliant examples and examples of houses that have been designed to be more energy efficient and exceed NZBC clause H1 *Energy efficiency* requirements.

Further information about these dwellings is provided in section 4.

During the development of the building information modelling (BIM) for these buildings, a list of materials was made that were missing from the material/product environmental database. This was used as the basis for obtaining data on environmental impacts. Additionally, a scan was made of available relevant EPDs and other sources of information that cover materials that may be found in residential construction.

As a result, the new materials and products listed in Table 2 have been added, divided into sections in Appendix A.

Table 2. New materials/products in material environmental impacts database v9.1.

Material type (Appendix A)	New material/product (names)
Aggregates	No additions
Clay (fired)	<u>Sanitary ware</u> • Ceramic basin sanitary ware (ceramic vitreous china) (basin - mass = 9 kg) • Ceramic basin sanitary ware (ceramic fine fire clay) (basin - mass = 9 kg) • WC, sanitary ware (ceramic vitreous china) (toilet - mass = 18 kg) • WC, sanitary ware (ceramic fine fire clay) (toilet - mass = 18 kg)
Concrete	No additions

[7] In 2016, BRANZ published material-specific scenario data available at www.branz.co.nz/buildinglca (and select "Data"), which includes the following: generic transport distances to construction sites in Auckland, Wellington and Christchurch (module A4), wastage rates at construction sites and end-of-life routes (module A5), maintenance (module B2), replacement (module B4) and building decommissioning and end-of-life routes (module C1). These defaults for stages in the life cycle other than manufacturing can be updated with provision of data from manufacturers. For details, see section 8 of the BRANZ Study Report SR349 (Dowdell and Berg, 2016).

Material type (Appendix A)	**New material/product (names)**
Fibre cement	No additions
Floor linings, excluding timber (interior)	• Anhydrite, levelling screed • Carpet - woven broadloom (pile material 500 - 600 g/m^2 polyamide 6.6, woven textile backing) • Carpet - woven broadloom (pile material 700 - 800 g/m^2 polyamide 6.6, woven textile backing) • Carpet - tufted wall-to-wall (pile material 1000 - 1100 g/m^2 80% wool and 20% polyamide 6.6, polyester (90% recycled) and textile fabric backing) • Carpet - tufted wall-to-wall (pile material 1300 - 1400 g/m^2 80% wool and 20% polyamide 6.6, polyester (90% recycled) and textile fabric backing) • Linoleum flooring • Vinyl (PVC) floor sheets
Glass and materials used in windows	• Window, IGU, glazing, argon
Insulation	<u>Glass wool</u> • Insulation (90 mm wall), Pink® Batts® Classic R1.8 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Classic R2.2 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Steel R2.2 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® R2.2 Narrow Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Classic R2.4 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® Steel R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® Steel R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Narrow Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Narrow Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.6 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Narrow Wall (glass wool) • Insulation (masonry wall), Pink® Batts® Masonry R1.0 (glass wool) • Insulation (masonry wall), Pink® Batts® Masonry R1.2 (glass wool) • Insulation (70 mm wall), Pink® Batts® Classic R2.2 70 mm Wall (glass wool) • Insulation (roof), Pink® Batts® Classic R1.8 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R2.2 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R2.6 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R3.2 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Skillion Roof R3.2 (glass wool) • Insulation (roof), Pink® Batts® Classic R3.6 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Skillion Roof R3.6 (glass wool) • Insulation (roof), Pink® Batts® Classic R4.0 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R5.0 Ceiling (glass wool)

Material type (Appendix A)	New material/product (names)
	• Insulation (roof), Pink® Batts® Classic R6.0 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R6.3 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R7.0 Ceiling (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R1.6 Narrow (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R1.6 Wide (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R2.6 Narrow (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R2.6 Wide (glass wool) • Insulation (acoustic, wall), Pink® Batts® Silencer® 100 mm (glass wool) • Insulation (acoustic, wall), Pink® Batts® Silencer® 75 mm (glass wool) • Insulation (acoustic, floor), Pink® Batts® Silencer® Midfloor (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R1.2 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R1.8 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R2.2 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R2.4 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R2.6 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R3.2 Blanket (glass wool) • Insulation (industrial (<350°C), light equipment insulation (LEI)), LEI Boards 50 mm (glass wool) • Insulation (industrial (<350°C), light equipment insulation (LEI)), LEI Boards 25 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 25 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 50 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 75 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 100 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Blanket 36 kg/m^3 (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Blanket 32 kg/m^3 (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 25 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 38 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 50 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 75 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 100 mm (glass wool) • Vacuum insulation panel
Membrane systems	• K-Dek with TPO membrane, 100 mm thick, R5.00 • K-Dek with PVC membrane, 100 mm thick, R5.00
Metals, and metal-containing composites	No additions
Paint	No additions
Plasterboard	No additions
Services and infrastructure	Elevators

Material type (Appendix A)	New material/product (names)
	• Elevator (30 floors) - thyssenkrupp momentum - rated load = 1588 kg, speed = 3.56 m/s • Elevator (12 floors) - thyssenkrupp synergy - rated load = 1588 kg, speed = 1.78 m/s • Elevator (5 floors) - thyssenkrupp evolution - rated load = 1000 kg, speed = 1.0 m/s • Elevator (3 floors) - thyssenkrupp endura machine room-less - rated load = 1134 kg, speed = 0.76 m/s • Elevator (14 floors) - OTIS Gen2 Stream High Rise® - rated load up to 1850 kg, speed up to 2.5 m/s • Elevator (12 floors) - OTIS Gen2 Stream® - rated load up to 2500 kg, speed up to 2.5 m/s • Elevator (5 floors) - OTIS Gen2 Life® - rated load up to 1000 kg, speed up to 1.6 m/s Water and drainage • PVC-U (unplasticised polyvinyl chloride), non-pressure pipes, exterior use • PVC-U (unplasticised polyvinyl chloride), non-pressure pipes, interior use
Timber and engineered wood	• Engineered wood, cross laminated timber (CLT) [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, glued laminated timber (glulam, softwood) [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 300x63 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 300x90 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 360x90 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 240x46 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 240x90 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 360x63 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Engineered wood, I-joist profile, 400x90 [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry]

Material type (Appendix A)	New material/product (names)
	• Engineered wood, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • MDF, thick, coated (average thickness 18 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) • MDF, thick, uncoated (average thickness 20 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) • MDF, thin, uncoated (average thickness 3 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) • Engineered wood, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, exterior cladding, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Post tensioned timber frame structure, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], inc. steel reinforcing • Timber, softwood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber, exterior cladding construction, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber wall framing, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber, structural framing, soft wood, dressed kiln-dried, interior use [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber structural framing, soft wood, dressed kiln-dried, exterior use [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Hardwood (dressed, kiln-dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings • MDF (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised nails (generic) • Particleboard (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings • Plywood (A-bond, floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings • Softwood (dressed kiln-dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings

Data for these materials were selected based on the data hierarchy in section 2.2.

3. Energy-related environmental impacts

3.1 New Zealand grid electricity

Section E1 of Appendix E in BRANZ Study Report SR350 (Berg et al., 2016) provided information about how the environmental impacts of New Zealand grid electricity were developed in LCAQuick v1.

Previously, a New Zealand grid electricity life cycle inventory (LCI) model developed by Sacayon Madrigal (Sacayon Madrigal) was used to calculate grid average impacts per kWh of low voltage electricity delivered, according to the sources of energy supplying the grid during the years 2012–2014 inclusive.

For example, this resulted in a 3-year average New Zealand grid greenhouse gas emission factor of 0.184 kg CO_2 eq./kWh low voltage electricity delivered.

In LCAQuick v1, the environmental impacts of grid electricity use were based on the modelled impacts from 2012–2014 supply, extrapolated forward for the service life of the building – for example, 60 years for office buildings (see Dowdell et al., 2016).

In LCAQuick v3.4 (and v3.3 before it), the following changes to the way environmental impacts associated with grid electricity use are calculated have been made:

- Environmental impact factors (per kWh) by source of energy were extracted from the Sacayon Madrigal (2015) New Zealand grid LCI model and transmission and distribution losses allocated to each energy source according to its contribution during the period 2015–2017.[8]
- The resultant impact factors were applied to the changing mix of energy sources forecast to 2050 and termed the Mixed Renewables scenario (MBIEMinistry of).
- Calculated environmental impacts due to the sources of energy supplying New Zealand grid electricity in 2050 were assumed to be maintained beyond 2050.
- The calculated environmental impacts by year of a building's service life are summed and divided by the number of years in its service life to derive impact factors (per kWh low voltage electricity delivered) that are applied to the annual energy demand for a building over its service life (usually derived from simulating the energy use in the building during design).

The Mixed Renewables scenario is "a mixture of geothermal and wind plant built, starting in 2020. This scenario assumes an average of 1% annual electricity demand growth, reflecting moderate GDP and population growth, and current views on relative technology cost and expected fuel and carbon prices" (MBIEMinistry of). It is one of five scenarios in the MBIE report, which was selected due to its conservative nature in comparison with other scenarios, which are based on higher GDP and population growth or high carbon price and lower cost renewables or reduction in technology costs or Tiwai Point closing.

[8] A limitation of this approach is that the allocation of environmental impacts arising from transmission and distribution is fixed, based on the contribution a specific fuel makes to the grid during the period 2015–2017. Thus, for a fuel with a declining share to 2050, this allocation will be over-represented and under-represented for a fuel with an increasing share. New research already being conducted will consider this issue so that the current method can be improved.

There are several implications of this change to the method, which are set out below:

- The original method did not consider a change in the proportion of renewables supplying grid electricity to New Zealand. This had the effect of showing a higher contribution of environmental impacts arising from energy use. The new method uses MBIE forecasts as a way of accounting for possible changes in the way energy is supplied to the grid, considering forecasts for GDP growth and population change. Due to the greater proportion of renewables forecast to supply grid electricity in the Mixed Renewables scenario, the contribution of energy use during the building service life reduces in comparison with the original method.
- Calculated environmental impacts will vary depending on the year in which the building service life commences, due to small differences in the contribution of energy sources supplying the grid from year to year. For the purposes of developing the reference office and residential buildings in LCAQuick v3.4, year 1 of the building service life is taken as 2020.
- Since the environmental impact of the grid marginally changes each year up to 2050, after which it is assumed to maintain the same environmental impacts as in year 2050, the calculated environmental impact factors vary marginally according to the service life of the building being assessed. Information about how the New Zealand grid is modelled is provided in Appendix B.

3.2 Heat

The means to account for provision of heat in LCAQuick v3.4 (and v3.3) has been expanded from LCAQuick v1 and is summarised in Table 3. Further information is provided in Appendix B.

Table 3. Summary of options in LCAQuick v3.4 for provision of heat.

Building typology	Source of heat	Basis for environmental impact factors	Notes
Commercial office	Natural gas	Per kWh at the meter	Includes pre-combustion. Impact factors based on a boiler (condensing, auto-ignition) with an efficiency of 89.8%.
	Landfill gas	Per kWh at the meter	Combustion efficiency assumed the same as for natural gas. An additional module D benefit is calculated, based on substitution of supply and combustion of propane (as a proxy for LPG).
Residential	Natural gas	Per kWh heat delivered	-
	Wood (mixed logs)	Per kWh heat delivered	Includes the following: • Start-stop and part-load operation – reduces efficiency and increases emissions. • Manufacture of a wood burner. • Transport of logs (assumed to be 100 km). • Release of biogenic carbon dioxide.

4. Reference residential buildings

Using the updated environmental data set out in sections 2 and 3, 12 reference residential buildings have been modelled using:

- BIM models developed according to the methodology in Berg et al., 2016)
- energy simulation according to the method set out in section 5 and using defaults provided in the updated module B6 datasheet (available at www.branz.co.nz/buildinglca (and select "Data").

Reference residential buildings comprise:

- three single-storey stand-alone houses designed for NZBC clause H1 compliance
- three single-storey stand-alone houses designed to exceed NZBC clause H1 requirements
- one double-storey stand-alone house designed for NZBC clause H1 compliance
- three double-storey stand-alone houses designed to exceed NZBC clause H1 requirements
- one medium-density housing (MDH) complex consisting of eight units designed for NZBC clause H1 compliance
- one high-density (apartment) building consisting of 108 units designed for NZBC clause H1 compliance and featuring two levels of retail (ground floor and first floor).

Summary information about the reference residential buildings is provided in Table 4. In the table, stand-alone houses designed for NZBC clause H1 compliance are numbered 1 to 4 and are organised from smallest to largest gross floor area. Similarly, stand-alone houses designed to (at least) exceed NZBC clause H1 compliance are numbered 5 to 10 and are also organised from smallest to largest gross floor area.

The elements included in the residential building models, derived from the BIM models used to obtain material quantities, are:

- foundations and ground floor construction or concrete floor slab
- external wall constructions including supporting structure
- internal wall constructions including supporting structure
- roof construction, including supporting structure
- windows (frame and glazing)
- doors (internal and external)
- painted surfaces (internal and external)
- floor coverings
- garages
- decks
- wash hand basin and toilet.

Currently excluded are:

- flashings
- spouting
- fixings (nails, nail plates etc.)
- sealants, glues and mastics

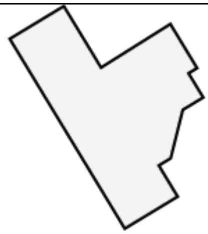
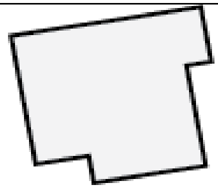
- scotias
- kitchen units, sink and cooker
- bathroom shower and bath
- plumbing and electrical
- hot water cylinder
- heat pump
- boiler, if present
- mechanical heating, cooling and air conditioning, including ducting, if present
- window and door furniture.
- kitchen and bathroom fans.

4.1 Estimated service life

The residential service life is taken as 90 years (Johnstone, 1994). In his paper, Johnstone states: "About 50% of dwellings have been lost from each dwelling cohort by the age of 90 years and the distribution of losses follows that of a bell shape skewed to the left." (Johnstone, 1994, p. 181).

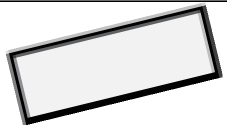
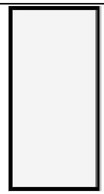
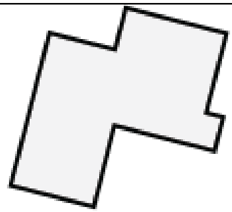
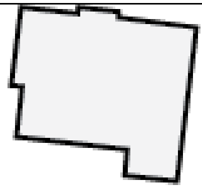
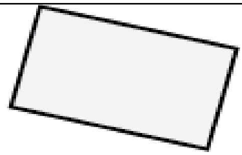
The same service life is used to represent MDH and apartments.

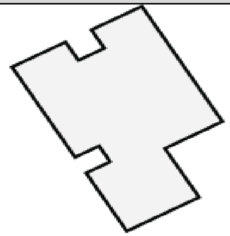
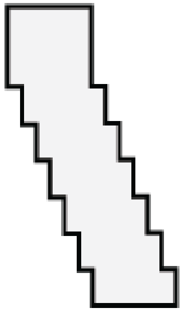
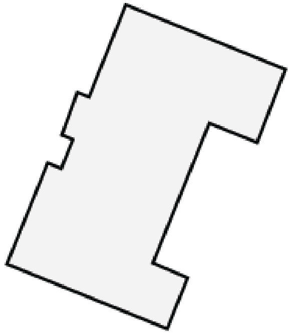
Table 4. Summary of new-build reference residential buildings.

ID code	Type	Designation[9]	Original location and zone	Floor plan and orientation[10]	Gross floor area (GFA) [m^2]	Treated floor area (TFA) [m^2]	No. of occupants (simulated)	Description
1	Stand-alone, single-storey	H1 compliant	Zone 2		120	120	4	NZS 3604 – timber
2	Stand-alone, single-storey	H1 compliant	Zone 2		166	118	4	NZS 3604 – timber
3	Stand-alone, single-storey	H1 compliant	Zone 1		194	156	5	NZS 3604 – timber
4	Stand-alone, double-storey	H1 compliant	Zone 1		194	157	5	NZS 3604 – timber

[9] All modelled buildings demonstrated H1 compliance for consenting purposes. In some cases, the framing ratio we apply in our modelling, which may be higher than was used for the purposes of demonstrating H1 compliance, can lead to calculated element level R-values that are slightly lower than required by clause H1.

[10] North is up the page, viewed as a landscape orientation. Not to scale.

ID code	Type	Designation[9]	Original location and zone	Floor plan and orientation[10]	Gross floor area (GFA) [m^2]	Treated floor area (TFA) [m^2]	No. of occupants (simulated)	Description
5	Stand-alone, single-storey	Exceeds H1	Zone 1		75	60	2	Specific design residential – SIPs
6	Stand-alone, double-storey	Exceeds H1	Zone 3		106	106	4	Specific design residential – CLT
7	Stand-alone, single-storey	Exceeds H1	Zone 3		113	113	4	NZS 3604 – timber
8	Stand-alone, single-storey	Exceeds H1	Zone 1		146	109	4	NZS 3604 – timber
9	Stand-alone, double-storey	Exceeds H1	Zone 2		186	152	5	Specific design residential – reinforced concrete

ID code	Type	Designation[9]	Original location and zone	Floor plan and orientation[10]	Gross floor area (GFA) [m²]	Treated floor area (TFA) [m²]	No. of occupants (simulated)	Description
10	Stand-alone, double-storey	Exceeds H1	Zone 3		190	157	4	NZS 3604 – timber
11	MDH (8 units)	H1 compliant	Zone 1		887	816	24	Braced frame and shear-wall frame system – reinforced concrete
12	Apartment (108 units + two floors of retail)	H1 compliant	Zone 2		4078	3388	189	Rigid frame system – reinforced concrete

5. Energy simulation

Residential buildings were energy simulated using defaults provided in the updated module B6 datasheet.[11] Energy simulations are carried out assuming the dwelling is operated to maintain a year-round comfortable temperature of between 18°C and 25°C to ensure it is warm, dry and healthy.

In New Zealand, use of dynamic energy simulation software such as EnergyPlus (as this study used) on residential buildings is rare. Consequently, there is no nationally accepted methodology available. This has resulted in several discrete simulation methods being used on an ad hoc basis by individual building simulation users, often with limited transparency and consistency between users. Critical simulation methodology gaps include:

- internal plug load power densities (electricity)
- internal lighting power densities (electricity)
- hot water energy use per occupant (electricity)
- natural ventilation modelling assumptions for bulk airflow models.

Therefore, for this research, a simulation method and quality assurance process was developed using Beacon Pathway's Waitakere NOW Home®, for which measured energy use data was available (Pollard et al., 2008), to check that the outputs of final energy simulations were reasonable. Once developed, the method was implemented on all other building models. This process was not a model calibration exercise. The intent was to develop a method and quality assurance process that could produce trustworthy results for indoor temperatures and energy use. Here, trustworthy results are defined as consistent and reasonable compared to our existing understanding of real New Zealand dwellings. This process consisted of the following.

Step 1

Organising the measured energy use data in Table 5 into aggregated energy end-use categories. For example, refrigeration, dishwasher, TV and jug became part of "Electrical equipment total". The results of this process are summarised in Table 6.

Step 2

Iteratively, energy simulations were carried out to obtain a final energy result, which included heating and cooling with an EnergyPlus airflow network including both infiltration and natural ventilation. The simulation was based on the NOW Home® having LED lighting[12] and operated to maintain a comfortable temperature range. The final simulated energy use data are presented in Table 7 and are compared with:

- the measured energy use data (from Table 6)
- an AccuRate model (developed independently for a previous BRANZ research project) that included lighting with incandescent bulbs (present in the NOW Home®).

[11] The datasheet is entitled "Operational energy (module B6) v2" and is located at www.branz.co.nz/buildinglca (then click the "Data" button).
[12] The NOW Home®, which was built in 2005, contains incandescent light bulbs. New houses built today are more likely to use LED lighting, so we model the lighting in the NOW Home® assuming it has LED lighting.

Table 5. Measured energy use data for the Beacon Pathway NOW Home®.

Energy end uses	% of total energy use
Solar hot water (SHW) boost	27
SWH pump	1
Heating	0
Range	4
Refrigeration	4
Lighting	6
Dishwasher	6
Water pump	2
Washing machine	<1
Home office computer	10
TV	5
Jug	1
Unknown	34
Total (kWh/year)	**8,500**
Total excl. hot water & lighting (kWh/year)	**5,610**

Table 6. Reorganised energy use measurement data for the Beacon Pathway NOW Home® for energy simulation output comparison.

Energy end uses	kWh per year	% of total energy use
Heating[13]	0	0
Cooling	0	0
Fans	0	0
Interior lighting	540	6
Electrical equipment total	5,580	66
SHW plug loads	2,380	28
Total measured energy use	**8,500**	**100**
Total energy use excluding hot water	**6,120**	**72**

Table 7. Final simulated Beacon Pathway NOW Home® energy use and comparisons.

Measured energy use			**Final energy simulation results**	**Check: AccuRate energy simulation**
Energy end use	Electricity (kWh/year)	% of total energy use	Electricity kWh per year (rounded)	Electricity kWh per year
Heating	0	0	279	279
Cooling	0	0	49	49
Fans	0	0	17	17
Lighting	540	6	304	862
Electrical equipment total	5,580	66	4,495	4,495
SHW plug loads	2,380	28	NA	NA
Hot water	-	-	2,550[14]	2,550
Total energy use	**8,500**	**100**	**7,694**	**8,252**
Energy use excluding hot water	**6,120**		**5,144**	**5,702**

[13] No energy was required for heating due to the passive design and internal heat gains (for example, from plugged in appliances).
[14] Electricity demand required to meet hot water needs calculated using EECA water heating systems tool Conversion of $ values to kWh based on 29c/kWh. (www.energywise.govt.nz/tools/water-heating/).

This check revealed the following:

- Simulated electricity use is within 1,000 kWh of measured electricity use (per year).
- Some electricity is required for heating and cooling, compared to no measured electricity use for these purposes. However, this difference can be explained due to the simulation representing a scenario where all rooms in the NOW Home® are maintained in the comfort range of 18–25°C year round. Measured year-round temperatures in the NOW Home® show that they are within the comfort range for a significant proportion of time but not all the time (Figure 1 and Figure 2) (Pollard et al., 2008), which would therefore require some space heating and cooling conditioning.
- Simulated lighting is lower than measured lighting as we assume use of LEDs rather than incandescent bulbs to reflect current (2019) building design. The AccuRate model check, which included use of incandescent bulbs, simulated a higher demand for electricity than was measured.
- Calculated electricity for hot water using EECA online Hot Water Systems tool is similar to the measured solar hot water plug loads.
- The largest difference between simulated and measured electricity use is in the "Electrical equipment total" category. Published standard schedules for plug loads were compared to the measured data, and on the basis of this comparison, NZS 4218:2009 *Thermal insulation – Housing and small buildings* was selected for simulating the plug loads. This section was based on its approximate alignment with the measured data (accepting uncertainties associated with occupant behaviour etc.), but also for consistency and transparency as NZS 4218:2009 details the simulation assumptions required by NZBC clause H1 under the verification modelling method. A review of other published plug load electric power densities included the following:
    - New Zealand Green Building Council's HomeStar (plug, lighting and occupancy) for a zone/space less than 25 m^2 uses internal heat gains of 4.1 W/m^2 as a constant internal load. More than 25 m^2 uses internal heat gains of "(2.1 W/m^2xInternal Floor Area+50 W)/(Internal Floor Area in m^2)".
    - NREL 2014 Building America House Simulation Protocols require a detailed calculation using their tool and the supplied energy use and load profile curves for different appliances.

Step 3

A passive variation of the model was created using the airflow network (bulk airflow modelling objects) but with no heating or cooling in order to check achieved indoor temperatures to see if they were reasonable in comparison with measured temperatures (Figure 1 and Figure 2). All zones were modelled and achieved maximum, 75th, 50th, 25th quartile and minimum temperatures that were similar to the recorded data. Average simulated temperatures from this passive simulation (compared to measured data reproduced from Figure 1 and Figure 2) are presented in Figure 3 and Figure 4.

Figure 1. Measured summer temperatures by room in the NOW Home®.[15]

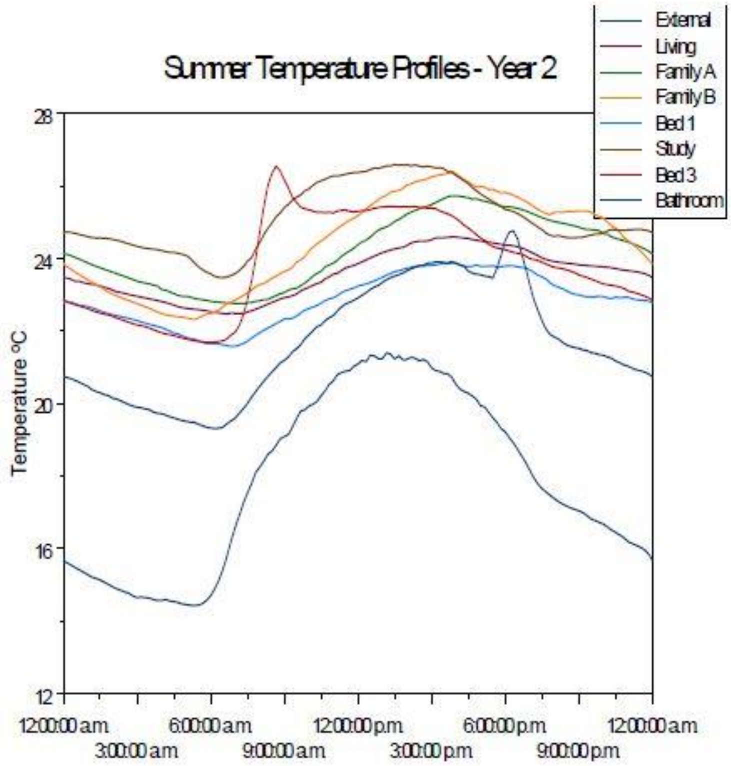
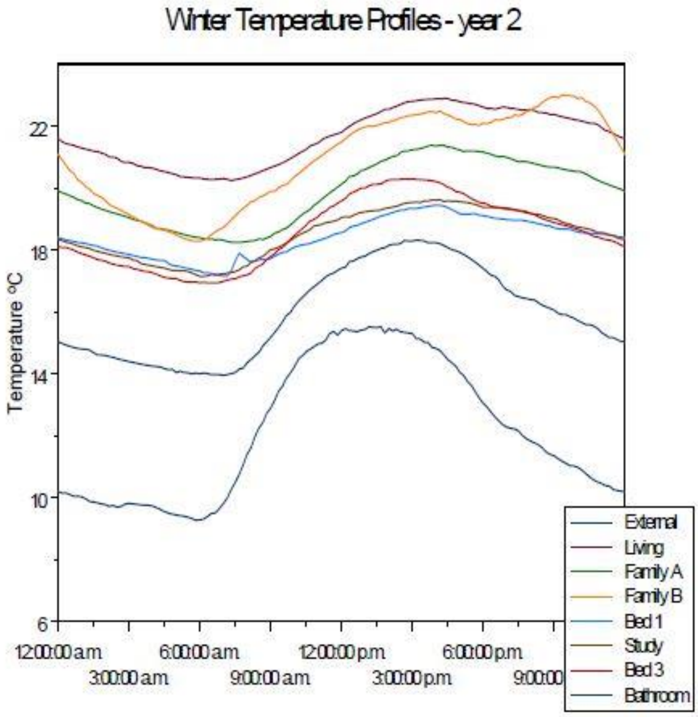


Figure 2. Measured winter temperatures by room in the NOW Home®.



[15] Pollard et al, 2008.

Figure 3. Measured (left) and simulated (right) summer temperatures for the NOW Home®.

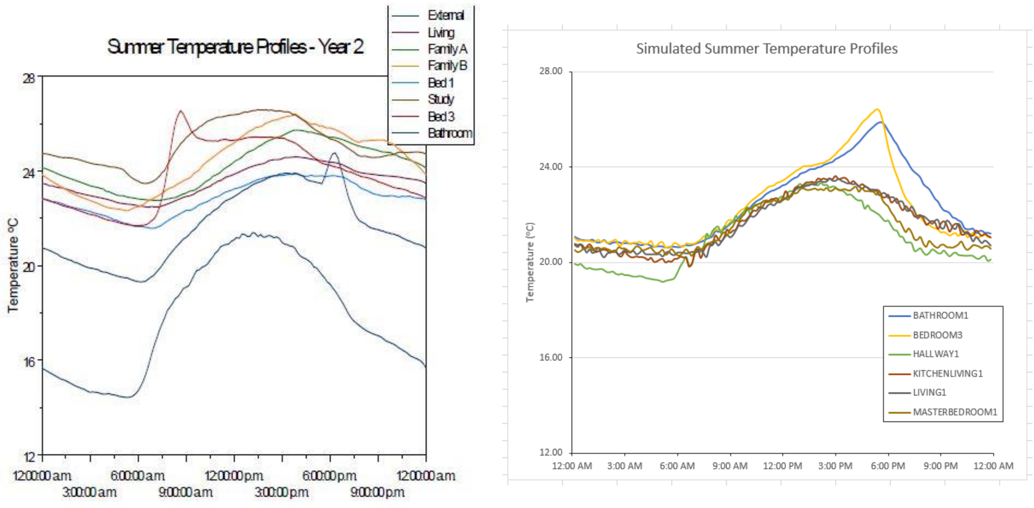
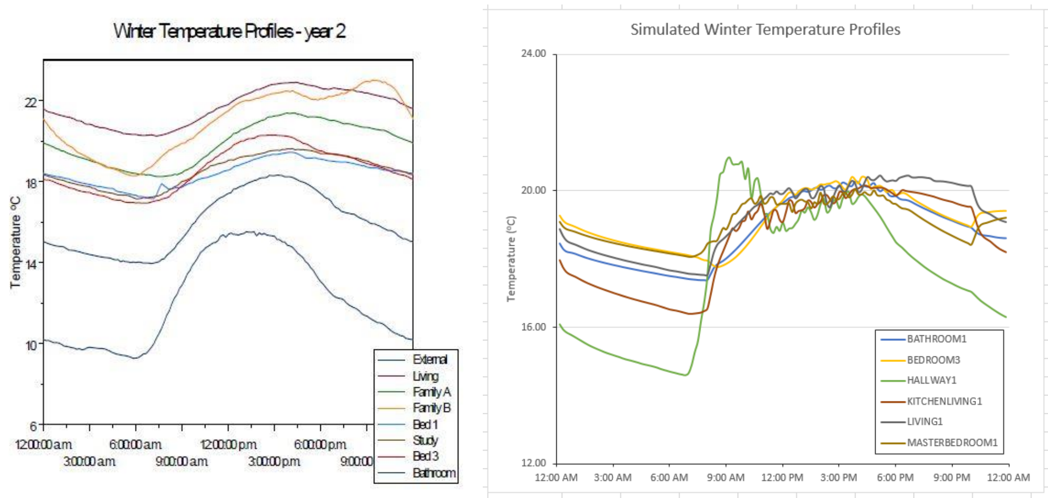


Figure 4. Measured (left) and simulated (right) winter temperatures for the NOW Home®.



Step 4

An infiltration test was carried out using variations of the passive model in which no natural ventilation was assumed, i.e. windows were closed to isolate airflow and heat loss due to infiltration. Predicted heat loss percentages were calculated:

- by hand using the NZS 4218:2009 calculation method.
- using the simple airflow model assuming a constant zone infiltration rate
- using the network airflow model to calculate an effective leakage area applied to the net wall area – the results of this check are presented in Table 8.

Step 5

Finally, the heating, cooling and fan energy demand using the simple airflow model (with constant infiltration and natural ventilation) was compared to the heating, cooling and fan energy demand derived from the airflow network model.

The results of this process are summarised in Table 9.

Table 8. Infiltration test results.

	Hand calculation	**Simple airflow model** Simulated constant zone infiltration rate (0.15 air changes per hour (ach) at 4 Pa in all exterior zones)	**Network airflow model** Simulated infiltration rate converted to an effective leakage area applied to net wall area (0.15 ach at 4 Pa in all exterior zones)
Heat loss %	6.0%	9.7%	10.6%
Average of zones average	N/A	0.15 ach	0.21 ach
Average of zones max.	N/A	0.16 ach	1.36 ach
Average of zones 75th	N/A	0.16 ach	0.27 ach
Average of zones 50th	N/A	0.15 ach	0.18 ach
Average of zones 25th	N/A	0.15 ach	0.13 ach
Average of zones min.	N/A	0.15 ach	0.01 ach

Table 9. Comparison of heating, cooling and fans energy using alternative airflow models (network and simple) with an active heat pump.

	Simple airflow model	**Network airflow model**
Heating (kWh)	167.5	279.1
Cooling (kWh)	558.29	48.91
Fans (kWh)	182.76	16.68

6. LCAQuick v3.4 updates

LCAQuick v3.4 contains features that were not previously available in LCAQuick v1:

- The ability to save and load building input data.
- A window/door builder.
- Material code identification tool.
- In terms of energy use, environmental impacts are now split between building integrated and tenant energy.
- A carbon budget analysis worksheet
- Green Star worksheet.

The following sections provide further information.

6.1 Saving and loading building input data

LCAQuick v3.4 is a large, complex spreadsheet (around 57 MB). It can be difficult to share complete LCAQuick projects outside of a computer network, as these spreadsheets are frequently too large for many email systems and uploading to cloud-based file systems is typically required.

A version of LCAQuick called LCAQuick v3.4 Data Entry has had the analysis calculations and reference building comparisons removed and so requires less calculation, providing a more responsive data entry process. However, these files are still large (around 38 MB) providing some input verification as well as lists of reference data and are still too large to easily share.

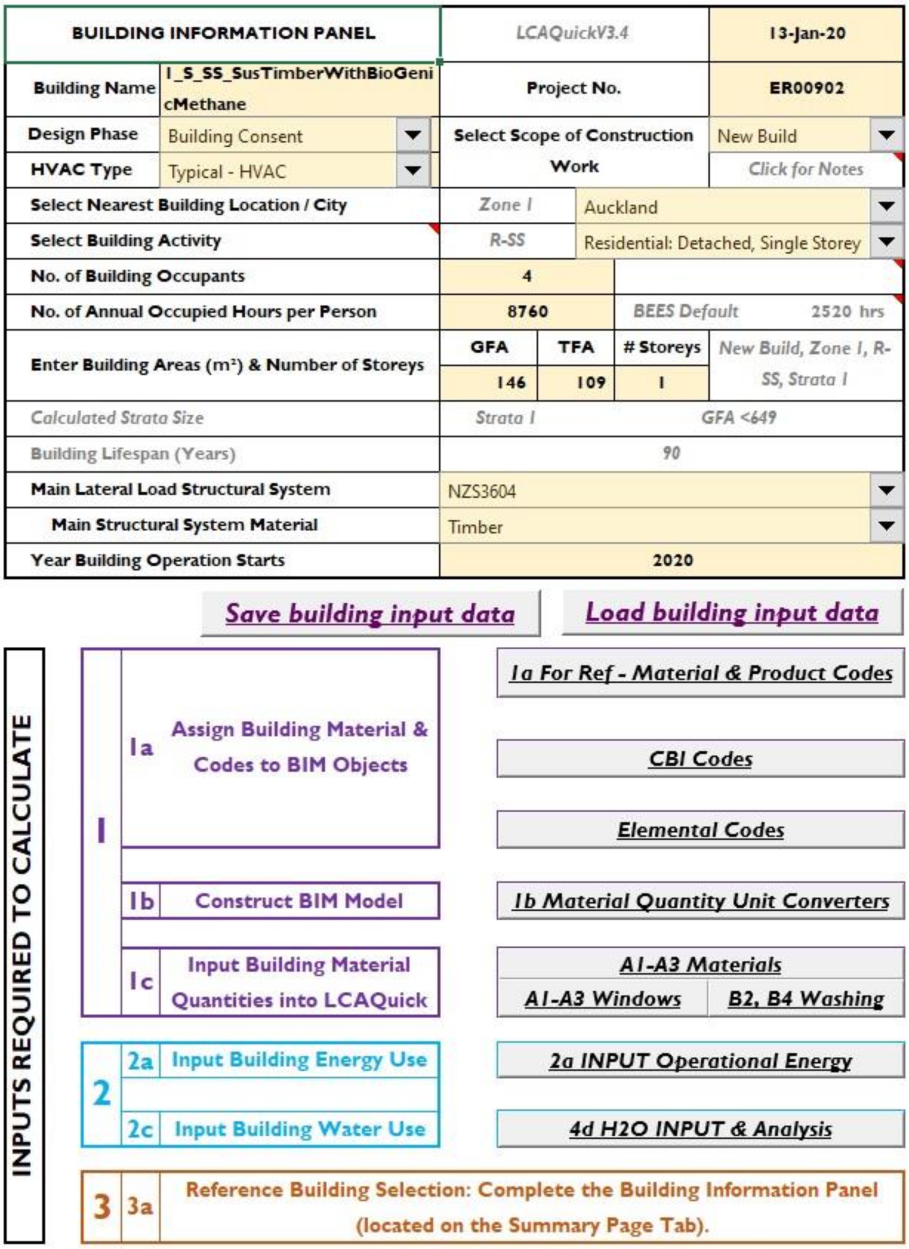
To more easily share LCA files between users, a new process to has been developed to save and load building input data. Figure 5 shows the locations of two new buttons located under the building information panel in the 4a_Summary Analysis worksheet. These two new buttons are called "Save building input data" and "Load building input data". The process for saving and loading building input data is the same for LCAQuick and LCAQuick Data Entry so comments in this section referring to LCAQuick can equally apply to LCAQuick Data Entry.

Building input data comprises data in the building information panel, material quantities data and the energy and water use data for a particular building. Building input data are shaded a cream colour to indicate that data are to be entered by the user. In addition, there are parts of LCAQuick that have user-entered data that are not part of the building input data, such as the input data for the window/door builder (see section 6.2).

The new "Save building input data" button copies the building input data in LCAQuick and saves it to a basic spreadsheet. This spreadsheet file is small (around 800 kB) and is saved in the normal Excel spreadsheet format (.xlsx) rather than the macro-enabled version (.xlsm), which is used for LCAQuick.

Building input data can be loaded into LCAQuick from either the building input data file or from an LCAQuick file that has building design information entered into it. To do this, press the "Load building input data" and then select the file from which the building input data is required.

Figure 5. Save and Load building input data buttons below the building information panel on the 4a_Summary Analysis sheet.



The structure of the data in the building input data file is a simplified and limited version of the data structure in LCAQuick. The data in the building input data file is read only, so if it needs to be modified, you need to open the building input data file in LCAQuick, make the required changes and then resave the building input data file (overwriting the previous file if desired). Data can be copied out of a building input data file such as when you wish to merge data together.

An example of when this functionality may be useful is provided below:

> A structural engineer develops the BIM for the structural engineering design using ArchiCAD. The architect on the same project develops the BIM for the architectural design using Revit.

The structural engineer can paste the schedule of quantities from their ArchiCAD model into LCAQuick, undertake the necessary data quality checks and click on the "Save building input data" button to create a building input file that summarises the material quantity information for the structure. The structural engineer can rename this file "Project XYZ_Structural.xlsx" and can email this to the architect.

The architect can use LCAQuick to paste the schedule of quantities from their Revit model into LCAQuick as well as add in the other data necessary for a building evaluation such as completion of the building information panel, results of energy simulation, water use. This LCAQuick file can be given a specific filename (for example, "Project XYZ_MASTER.xlsm"). A building input data file could also be saved ("Project XYZ_MASTER.xlsx") but this would need to be loaded each time LCAQuick is opened.

With the "Project XYZ_MASTER" open in LCAQuick, the architect can open the building input data file "Project XYZ_Structural.xlsx" from the structural engineer directly in Excel. The architect can then navigate within this building input data file to locate the structural materials the structural engineer has entered on the "1c INPUT – Material Quant." sheet, copy the list and then navigate back to the open LCAQuick spreadsheet and paste these materials at the end of the list the architect has generated on the "1c INPUT – Material Quant." sheet. The LCAQuick spreadsheet would now contain the complete results from both the structural engineer and the architect.

6.2 Window/door builder

Prior to LCAQuick v3.4, the user was required to calculate the material quantity of windows/glass doors using the cross-sectional area of manufacturers' window profiles and a manual calculation method. This process can often be time-consuming and difficult, particularly during early design stages.

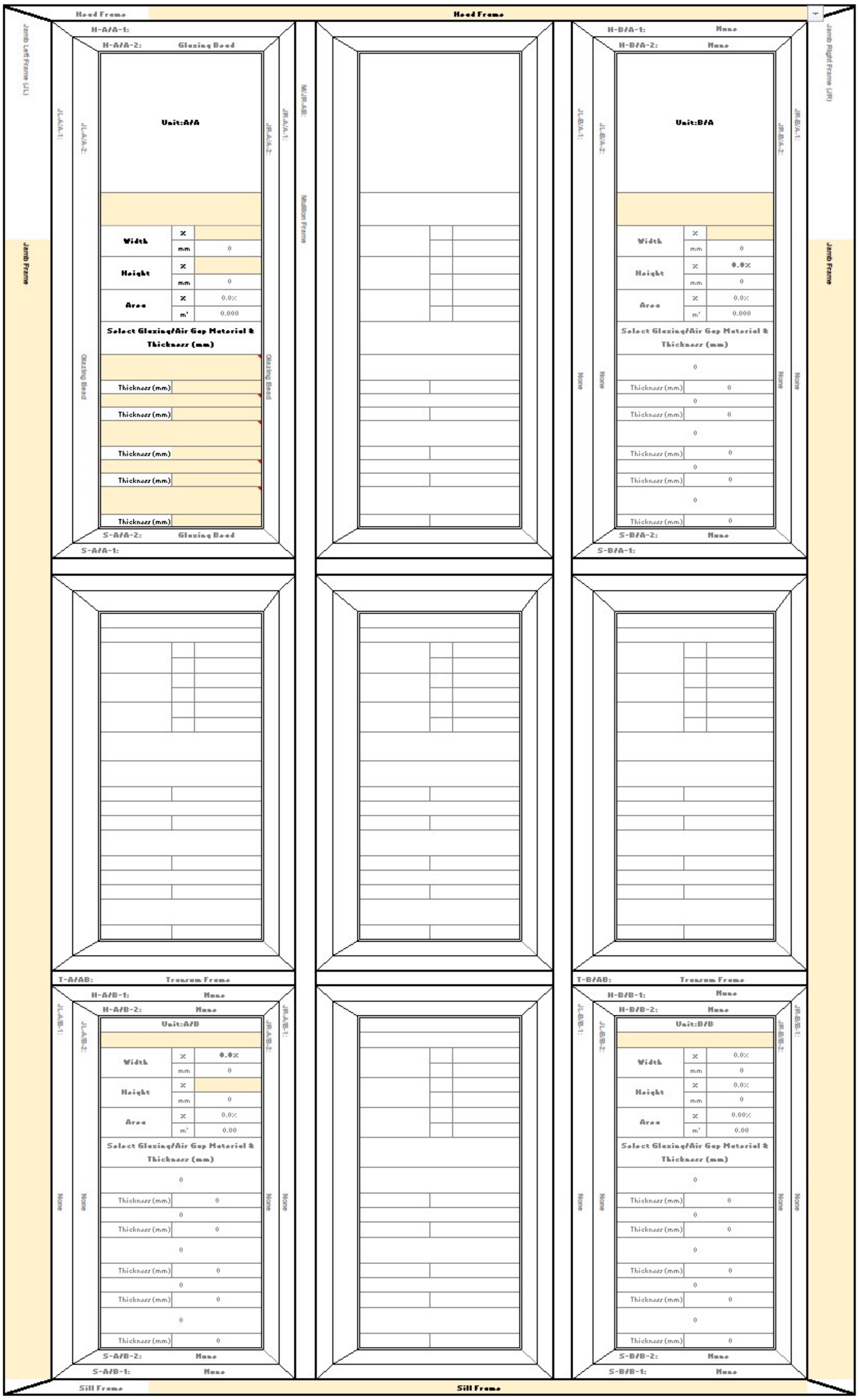
A window/door builder has now been included in LCAQuick v3.4 giving the user a simpler method of estimating material quantities during early design phases.

The window/door builder is a new worksheet (named "INPUT – Window Door Builder") that takes users through the following 7-step process to model a single window/door:

1. **Select Joinery Type** – select whether a window or door is being modelled.
2. **Select Joinery Style** – specify what type of window/door is being modelled.
3. **Enter Window/Door Unit Name** – specify the name of the window/door being modelled.
4. **Select Joinery Frame Material** – select what material is being used for the framing. Currently only aluminium, thermally broken aluminium, PVC and timber are available.
5. **Select Paint type (Primer)** and **Select Paint Type (Top Coat)** – select whether the framing is primed and painted.
6. **Enter Overall Width** – specify the total width of the whole window/door.
7. **Enter Overall Height** – specify the total height of the whole window/door.

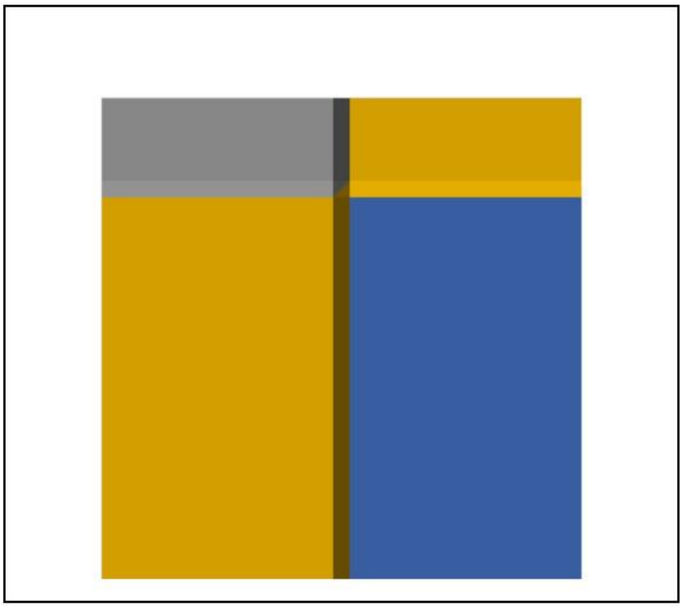
At this stage, the framing for a 1x1 unit has been modelled, where one unit is one pane of glass. The user then needs to specify the size of each pane and what glazing has been used. Figure 6 shows the panel (from LCAQuick v3.4) that is used to do this.

Figure 6. Window sizing pane from LCAQuick v3.4.



Each unit is sized based on a percentage of the overall width/height and assumes that the framing between them is 20 mm thick. The type of glazing is built up by specifying what type of glass and fill has been used and the thickness of these variables. The window/door builder also displays an illustrative sketch of the modelled window/door, an example of which is shown in Figure 7.

Figure 7. Illustrative sketch of a modelled window in LCAQuick v3.4.



The estimated material quantities for the modelled window are output into "Table 1: Generated Window / Door Schedule of Quantities", after which they can be copied into the "INPUT – Window Mat Quant." sheet. The outputs can be copied multiple times to represent multiple windows of the same type, but different types of windows need to be modelled separately.

The maximum single size the calculator can consider is a 3x3 unit. Where windows or doors are larger than 3x3 (say 1x4), assessment of the designed unit must be divided.

The window/door builder is designed to estimate the quantities of materials for early design. It is a simplified tool that does not cover every frame or glazing variant available and does not cater for non-rectangular shaped units.

6.3 Material code identification tool

The material data embedded in LCAQuick uses the NBS Uniclass "Products" coding system to categorise materials. A set of filters has been included in LCAQuick v3.4's material library on sheet "1a For Ref - Material Codes" to help users find material codes more easily by filtering products at different levels of the coding system. This allows users to find groups of materials at different levels of granularity based on what categories they belong too rather than having to search by name. This makes it less likely that users will not be able to find appropriate materials due to having different naming conventions from LCAQuick.

Figure 8 shows an example of the filtering lists available. Filtering at PR Code Level 4 will show the most general list of materials available, with each subsequent level showing more specific materials. Each material also shows the name of the category it belongs to at each of level of the system to give the user examples of the granularity of each level.

For example, searching for "Concrete, 17.5 MPa" in filtering level 4 will show all materials in 17.5 MPa concrete. Subsequent levels can be used to refine the search further based on casting type, amount of reinforcing and cement mixture.

Figure 8. Example of filtering lists available in LCAQuick v3.4 to find material codes.

Filter Search Criteria. Use the Drop Down Menu/Filters to search for materials.					
PR Code Level 4 Filter	PR Code Level 5 Filter	PR Code Level 6 Filter	PR Code Level 7 Filter	PR Code Level 8 Filter	Concrete Steel Reinforcement & Cement Replacement Filter
Clay fill	Clay fill	Clay fill	Clay fill	Clay fill	
Granular fill	Granular fill	Granular fill	Granular fill	Granular fill	
Sand	Sand	Sand	Sand	Sand	
Low density polyethylene (PE-LD) geomembranes	Membrane, polyethylene (PE)	Membrane, polyethylene (PE)	Membrane, polyethylene (PE)	Membrane, polyethylene (PE)	
Carbon steel rods	Steel reinforcement, primary, bar (Pacific Steel)	Steel reinforcement, primary, bar (Pacific Steel)	Steel reinforcement, primary, bar (Pacific Steel)	Steel reinforcement, primary, bar (Pacific Steel)	
Concrete, 17.5 MPa	Concrete, 17.5 MPa, in-situ	Concrete, 17.5 MPa, in-situ, no reinforcement	Concrete, 17.5 MPa, in-situ, no reinforcement, (OP	Concrete, 17.5 MPa, in-situ, no reinforcement, (OP	Concrete, 17.5 MPa, in-situ, no reinforcement, (OPC)
Concrete, 17.5 MPa	Concrete, 17.5 MPa, in-situ	Concrete, 17.5 MPa, in-situ, no reinforcement	Concrete, 17.5 MPa, in-situ, no reinforcement, GGB	Concrete, 17.5 MPa, in-situ, no reinforcement, GGB	Concrete, 17.5 MPa, in-situ, no reinforcement, (25% GGBS)
Concrete, 17.5 MPa	Concrete, 17.5 MPa, in-situ	Concrete, 17.5 MPa, in-situ, no reinforcement	Concrete, 17.5 MPa, in-situ, no reinforcement, GGB	Concrete, 17.5 MPa, in-situ, no reinforcement, GGB	Concrete, 17.5 MPa, in-situ, no reinforcement, (50% GGBS)
Concrete, 17.5 MPa	Concrete, 17.5 MPa, in-situ	Concrete, 17.5 MPa, in-situ, no reinforcement	Concrete, 17.5 MPa, in-situ, no reinforcement, GGB	Concrete, 17.5 MPa, in-situ, no reinforcement, GGB	Concrete, 17.5 MPa, in-situ, no reinforcement, (75% GGBS)
Concrete, 17.5 MPa	Concrete, 17.5 MPa, in-situ	Concrete, 17.5 MPa, in-situ, no reinforcement	Concrete, 17.5 MPa, in-situ, no reinforcement, PFA	Concrete, 17.5 MPa, in-situ, no reinforcement, PFA	Concrete, 17.5 MPa, in-situ, no reinforcement, (20% PFA)
Concrete, 17.5 MPa	Concrete, 17.5 MPa, in-situ	Concrete, 17.5 MPa, in-situ, no reinforcement	Concrete, 17.5 MPa, in-situ, no reinforcement, PFA	Concrete, 17.5 MPa, in-situ, no reinforcement, PFA	Concrete, 17.5 MPa, in-situ, no reinforcement, (35% PFA)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	50 kg/m3 steel reinforcing, (OPC)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	50 kg/m3 steel reinforcing, (25% GGBS)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	50 kg/m3 steel reinforcing, (50% GGBS)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	50 kg/m3 steel reinforcing, (75% GGBS)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	50 kg/m3 steel reinforcing, (20% PFA)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m3	50 kg/m3 steel reinforcing, (35% PFA)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	100 kg/m3 steel reinforcing, (OPC)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	100 kg/m3 steel reinforcing, (25% GGBS)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	100 kg/m3 steel reinforcing, (50% GGBS)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	100 kg/m3 steel reinforcing, (75% GGBS)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	100 kg/m3 steel reinforcing, (20% PFA)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m	100 kg/m3 steel reinforcing, (35% PFA)
Concrete, 17.5 MPa	Reinforced concrete, 17.5 MPa, in-situ	Reinforced concrete, 17.5 MPa, in-situ, inc. 150 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 150 kg/m	Reinforced concrete, 17.5 MPa, in-situ, inc. 150 kg/m	150 kg/m3 steel reinforcing, (OPC)

6.4 Split between building-integrated and tenant energy

In LCAQuick v3.4, the energy use inputs in sheet "2a INPUT PASTE - Energy Use" have been separated into three categories based on the reporting requirements outlined in EN 15978. Examples of the categories and expected inputs for each are summarised in Table 10.

Category 3 covers energy used by tenants. This category is only used for commercial buildings and is not included in the scope of building life cycle assessment in Green Star.

Table 10. Energy demand categories used in LCAQuick v3.4.

Category number	Category name	Includes (examples)
1	Building-integrated technical systems per EN 15603 (CEN, 2008)	• Plug load/small power equipment • Interior lighting • Hot water • Heating • Cooling/humidification/dehumidification • Mechanical ventilation • Fans • Pumps
2	Building-integrated technical systems outside scope of EN 15603)	• Lift/elevator • Safety and security • Communication systems
3	Tenancy/non-building related	• Tenant plug loads/small power equipment • Tenant lighting • Tenant HVAC (tenant-installed specific systems)

6.5 Carbon budget analysis worksheet

Massey University and BRANZ scientists have developed a model to calculate carbon budgets for new New Zealand buildings.[16] These carbon budgets take a 'planetary boundary' approach, which translates total global greenhouse gas emissions that may be emitted to 2050 to keep the global temperature rise above pre-industrial levels to no more than 2°C or 1.5°C and reflects these on a 'per new building' level, which is more meaningful to architects, designers and their clients.

The carbon budget models have multiple inputs and require further research so are dynamic and may change in the future.

A worksheet called "4e Carbon Budget Analysis" has been added to LCAQuick v3.4 in which the calculated carbon budgets for 2°C and 1.5°C of warming above pre-industrial levels are displayed in comparison with the carbon footprint of the designed building (in graph M).[17]

[16] Currently, carbon budgets have been calculated for residential and commercial office typologies only.
[17] LCAQuick v3.3 was made available on the BRANZ website in September 2019. This version excluded the carbon budget analysis.

The carbon budgets are calculated using information entered in the building information panel, specifically, the building activity, gross floor area and occupancy.

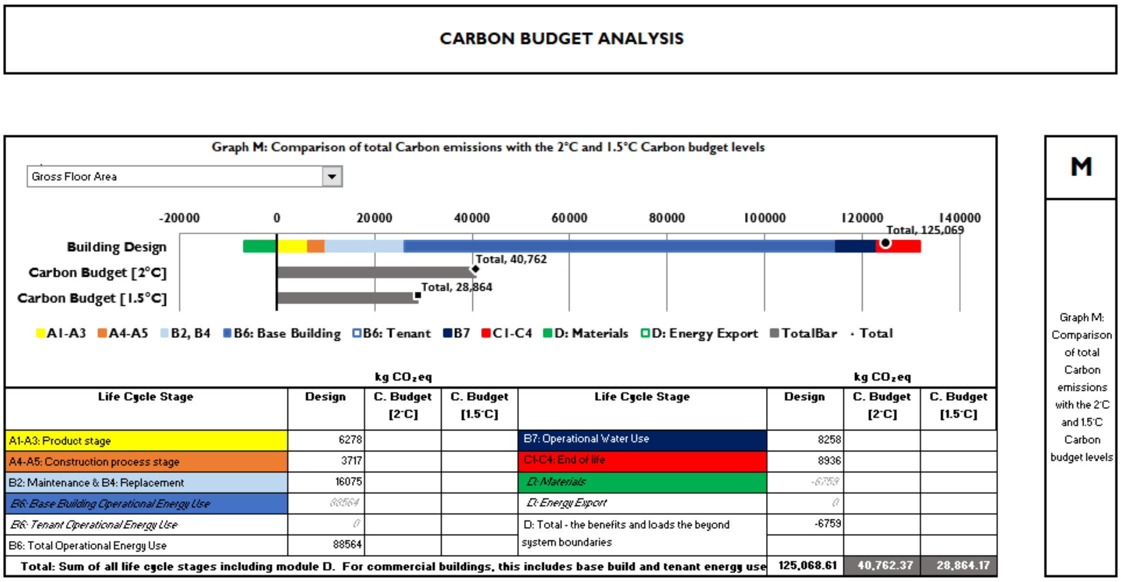
The user can toggle between carbon budgets derived from gross floor area (or occupancy for residential typologies) using the drop-down menu provided. Note that a carbon budget displayed on a gross floor area basis will be different to a carbon budget based on occupancy. The user can decide on which basis the evaluation is made.

We suggest that the carbon budget for 1.5°C of warming above pre-industrial levels is used. This aligns with the target in the New Zealand Climate Change Response (Zero Carbon) Amendment Act.

Similarly, the user needs to consider carefully when deciding between use of floor area or occupancy for deriving a carbon budget. For example, a proposed house with a 200 m^2 floor area will have the same carbon budget when considered on a floor area basis (which does not consider occupancy). However, the carbon budget for this same house will be different if presented on an occupancy basis for a family of five compared to a couple.

The climate change impacts calculated for the design and carbon budgets are summarised in a table under the graph. Since the carbon budget is based on an absolute rather than a comparison approach, the results can only be viewed in terms of total greenhouse gas emissions.

Figure 9. Screenshot of the carbon budget analysis worksheet in LCAQuick v3.4.



Life Cycle Stage	Design (kg CO_2eq)	C. Budget [2°C]	C. Budget [1.5°C]	Life Cycle Stage	Design (kg CO_2eq)	C. Budget [2°C]	C. Budget [1.5°C]
A1-A3: Product stage	6278			B7: Operational Water Use	8258		
A4-A5: Construction process stage	3717			C1-C4: End of life	8936		
B2: Maintenance & B4: Replacement	16075			D: Materials	-6759		
B6: Base Building Operational Energy Use	88564			D: Energy Export	0		
B6: Tenant Operational Energy Use	0			D: Total - the benefits and loads the beyond system boundaries	-6759		
B6: Total Operational Energy Use	88564						
Total: Sum of all life cycle stages including module D. For commercial buildings, this includes base build and tenant energy use					125,068.61	40,762.37	28,864.17

6.6 Green Star worksheet

A worksheet entitled "Green Star Outputs" has been added to LCAQuick v3.4. This worksheet is useful for those that are using LCAQuick to target the building life cycle assessment points in NZGBC's Green Star Design and As Built tool (credit 19A). When targeting the building LCA points in Green Star, NZGBC requires that its "Green Star 19A_life-cycle-assessment-calculator-NZv1.0 tool" (available from the NZGBC website) is populated in order that the potential points available as a result of a comparison between the designed and reference buildings, are calculated consistently.

The results of the LCAQuick assessment are populated in this worksheet, which is designed to look like NZGBC's calculator tool. Light blue sections of the tables in this worksheet can be copied and pasted into the NZGBC calculator tool, which will then calculate the potential points.

An accompanying editable PDF building LCA report template is also separately available from the BRANZ website,[18] which can be used when targeting these points (this was also available with LCAQuick v1 but has been updated).

[18] Available from the "LCAQuick and Green Star" page at www.branz.co.nz/cms_display.php?st=1&pg=23290&sn=415&forced_id=yes

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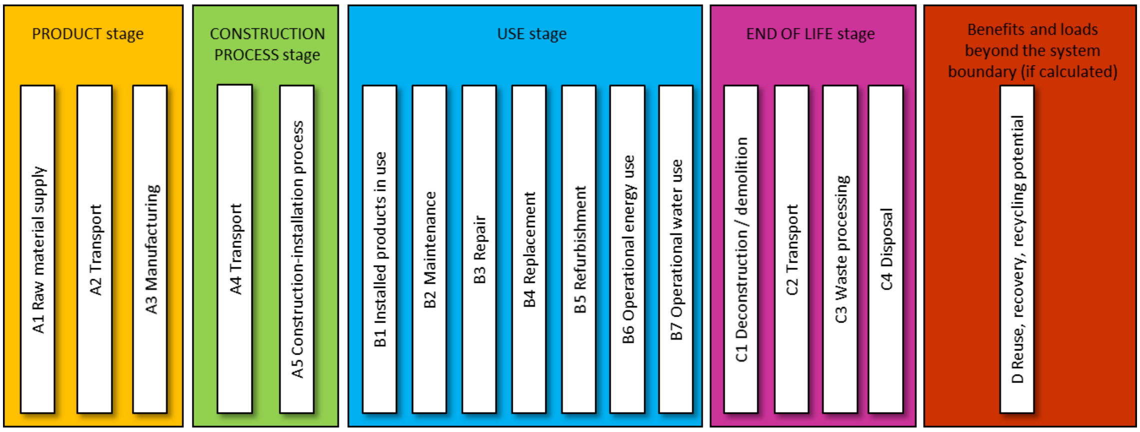
Appendix A: Materials/products environmental data

This section provides information on the source and derivation of calculated environmental indicator values by material and stage in the building life cycle. It is divided into the following sections dealing with each of the stages in the building life cycle:

- Section A1: Product stage (modules A1–A3)
- Section A2: Construction process stage (modules A4–A5)
- Section A3: Use stage (modules B2 and B4)
- Section A4: End-of-life stage (modules C1–C4)
- Section A5: Supplementary information beyond the building life cycle (module D)

The module numbers above are based on the description of the building life cycle in EN 15978 from which Figure 10 is based. These module numbers are referenced throughout this section.

Figure 10. Description of the building life cycle.



A1. Product stage (modules A1–A3)

Set out below is supporting information for the source and derivation of environmental indicators for modules A1–A3 for a range of materials that may be considered at concept or preliminary design or further into the design process.

Information is provided under the following headings and is organised alphabetically by product name under each heading.

Material type	List of materials modelled
A1.1 Aggregates	• Granular fill • Sand • Clay fill
A1.2 Clay (fired)	• Brick (clay) • Tiles (ceramic) Sanitary ware • Ceramic basin sanitary ware (ceramic vitreous china) (basin - mass = 9 kg)

	• Ceramic basin sanitary ware (ceramic fine fire clay) (basin - mass = 9 kg) • WC, sanitary ware (ceramic vitreous china) (toilet - mass = 18 kg) • WC, sanitary ware (ceramic fine fire clay) (toilet - mass = 18 kg)
A1.3 Concrete	<u>Autoclaved aerated concrete</u> • Autoclaved aerated concrete (AAC) blocks • Autoclaved aerated concrete (AAC), precast block, density 525 kg/m^3, exc. steel reinforcing. • Autoclaved aerated concrete (AAC), precast block, density 650 kg/m^3, exc. steel reinforcing. <u>Concrete, block (masonry wall)</u> • Concrete blocks, 17.5 MPa • Masonry wall, incl. concrete block 15 series (17.5 MPa OPC), grouted 22 MPa (OPC), inc. steel reinforcing • Masonry wall, incl. concrete block 20 series (17.5 MPa OPC), grouted 22 MPa (OPC), inc. steel reinforcing • Masonry wall, incl. concrete block 25 series (17.5 MPa OPC), grouted 22 MPa (OPC), inc. steel reinforcing <u>Concrete, in-situ (made with OPC), unreinforced and reinforced</u> • Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC) at 17.5, 20, 25, 30, 35, 40, 45 and 50 MPa compressive strengths • Reinforced concrete (25, 30, 35, 40, 45 and 50 MPa), composite floor decking, trapezoidal deck section 75 mm and 95 mm deep troughs at 300 mm ctrs, in-situ slab (at 125, 130, 140, 150, 160, 170, 180 and 200 mm thicknesses), inc. 100 and 150 kg/m^3 steel reinforcing, OPC <u>Concrete, in-situ (made with secondary cementitious material), unreinforced and reinforced</u> • Unreinforced and reinforced in-situ concrete with secondary cementitious replacements at 17.5, 20, 25, 30, 35, 40, 45 and 50 MPa compressive strengths • Reinforced concrete (25, 30, 35, 40, 45 and 50 MPa), composite floor decking, trapezoidal deck section 75 mm and 95 mm deep troughs at 300 mm ctrs, in-situ slab (at 125, 130, 140, 150, 160, 170, 180 and 200 mm thicknesses), inc. 100 and 150 kg/m^3 steel reinforcing, with secondary cementitious replacements <u>Concrete, precast, reinforced</u> • Reinforced precast concrete made with Ordinary Portland Cement (OPC) at 30 MPa and 45 MPa compressive strengths • Reinforced precast concrete made with secondary cementitious replacements at 30 MPa and 45 MPa compressive strengths <u>Concrete, precast, reinforced (double tee)</u> • Reinforced concrete, 45 MPa, precast double-tee, inc. 200 kg/m^3 steel reinforcing (200, 250, 300, 350, 400, 450, 500, 550, 600 series), OPC • Reinforced concrete, 45 MPa, precast double-tee, inc. 200 kg/m^3 steel reinforcing (200, 250, 300, 350, 400, 450, 500, 550, 600 series), with secondary cementitious replacements <u>Concrete, precast, reinforced (hollow core)</u> • Reinforced concrete, 50 MPa, precast hollow core, inc. 50 kg/m^3 steel reinforcing (200, 300, 400 series), OPC • Reinforced concrete, 50 MPa, precast hollow core, inc. 50 kg/m^3 steel reinforcing (200, 300, 400 series), with secondary cementitious replacements <u>Concrete (tiles)</u> • Roof tiles, concrete

	Grout • Grout, masonry infill, 22 MPa Mortar • Mortar Plaster • Plaster, cement
A1.4 Fibre cement	• Cladding, James Hardie HardieFlex™ (fibre cement, 6.0 mm thickness) • Cladding, James Hardie HardieFlex™ (fibre cement, 7.5 mm thickness) • Cladding, weatherboard, all profiles (fibre cement, 7.5 mm thickness) • Cladding, weatherboard, all profiles (fibre cement, 16 mm thickness) • Cladding, James Hardie EasyLap™ panel (fibre cement, 8.5 mm thickness) • Cladding, all profiles (fibre cement, 9 mm thickness) • Cladding, all profiles (fibre cement, 14 mm thickness) • Flooring, compressed sheet (fibre cement, 18 mm thickness) • Flooring, interior or exterior (fibre cement, 19 mm thickness) • Flooring, underlay (fibre cement, 6 mm thickness) • Interior wall lining (fibre cement, 4.5 mm thickness) • Interior wall lining (fibre cement, 6 mm thickness) • Interior wall lining (fibre cement, 7.5 mm thickness) • Interior wall lining (fibre cement, 9 mm thickness) • Rigid air barrier (fibre cement, 4.5 mm thickness) • Rigid air barrier (fibre cement, 6 mm thickness) • Rigid air barrier (fibre cement, 9 mm thickness) • Soffit / eaves lining (fibre cement, 4.5 mm thickness) • Soffit / eaves lining (fibre cement, 6 mm thickness) • Soffit / eaves lining (fibre cement, 7.5 mm thickness) • Soffit / eaves lining (fibre cement, 9 mm thickness)
A1.5 Floor linings, excluding timber (interior)	• Anhydrite, levelling screed • Carpet - woven broadloom (pile material 500 - 600 g/m^2 polyamide 6.6, woven textile backing) • Carpet - woven broadloom (pile material 700 - 800 g/m^2 polyamide 6.6, woven textile backing) • Carpet - tufted wall-to-wall (pile material 1000 - 1100 g/m^2 80% wool and 20% polyamide 6.6, polyester (90% recycled) and textile fabric backing) • Carpet - tufted wall-to-wall (pile material 1300 - 1400 g/m^2 80% wool and 20% polyamide 6.6, polyester (90% recycled) and textile fabric backing) • Linoleum flooring • Vinyl (PVC) floor sheets
A1.6 Glass and materials used in windows	Aluminium • Curtain wall extruded frame (aluminium, primary (anodised finish)) • Curtain wall extruded frame (aluminium, primary (powder coated finish)) • Window frame (aluminium, primary (anodised finish), non-thermally broken) • Window frame (aluminium, primary (powder coated finish), non-thermally broken) • Window frame (aluminium, primary (anodised finish), thermally broken) • Window frame (aluminium, primary (powder coated finish), thermally broken)

	Argon • Window, IGU, glazing, argon Glass • Glass, single pane, heat strengthened • Glass, single pane, heat strengthened, low emissivity (low-E) finish • Glass, single pane, laminated • Window, IGU, glazing (float glass) • Window, IGU, glazing (float glass, low emissivity (Low-E) finish • Window, IGU, glazing (glass, heat strengthened) • Window, IGU, glazing (glass, heat strengthened, low emissivity (low-E) finish PVC-U • Window frame (PVC-U) Softwood • Window frame (soft wood [from sustainable forest management practices]), unpainted (indoor/outdoor) • Window frame (soft wood [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]), unpainted (indoor/outdoor)
A1.7 Insulation	Specific data • Insulation (90 mm wall), Pink® Batts® Classic R1.8 Wall (glass wool) • Insulation (90 mm wall Pink® Batts® Classic R2.2 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Steel R2.2 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® R2.2 Narrow Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Classic R2.4 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® Steel R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® Steel R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Narrow Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Narrow Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.6 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Narrow Wall (glass wool) • Insulation (masonry wall), Pink® Batts® Masonry R1.0 (glass wool) • Insulation (masonry wall), Pink® Batts® Masonry R1.2 (glass wool) • Insulation (70 mm wall), Pink® Batts® Classic R2.2 70 mm Wall (glass wool) • Insulation (roof), Pink® Batts® Classic R1.8 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R2.2 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R2.6 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R3.2 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Skillion Roof R3.2 (glass wool) • Insulation (roof), Pink® Batts® Classic R3.6 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Skillion Roof R3.6 (glass wool) • Insulation (roof), Pink® Batts® Classic R4.0 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R5.0 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R6.0 Ceiling (glass wool)

	• Insulation (roof), Pink® Batts® Classic R6.3 Ceiling (glass wool) • Insulation (roof), Pink® Batts® Classic R7.0 Ceiling (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R1.6 Narrow (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R1.6 Wide (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R2.6 Narrow (glass wool) • Insulation (floor), Pink® Batts® SnugFloor® R2.6 Wide (glass wool) • Insulation (acoustic, wall), Pink® Batts® Silencer® 100 mm (glass wool) • Insulation (acoustic, wall), Pink® Batts® Silencer® 75 mm (glass wool) • Insulation (acoustic, floor), Pink® Batts® Silencer® Midfloor (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R1.2 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R1.8 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R2.2 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R2.4 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R2.6 Blanket (glass wool) • Insulation (blanket, roof), Pink® Batts® BIB R3.2 Blanket (glass wool) • Insulation (industrial (<350°C), light equipment insulation (LEI)), LEI Boards 50 mm (glass wool) • Insulation (industrial (<350°C), light equipment insulation (LEI)), LEI Boards 25 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 25 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 50 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 75 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 100 mm (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Blanket 36 kg/m^3 (glass wool) • Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Blanket 32 kg/m^3 (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 25 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 38 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 50 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 75 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 100 mm (glass wool) Generic data • Insulation, glass wool (generic) • Insulation, mineral wool • Insulation, polyester • Insulation, polystyrene expanded (EPS)

	• Insulation, polystyrene extruded (XPS) • Insulation underslab, polystyrene extruded (XPS) • Vacuum insulation panel
A1.8 Membrane systems	• Bitumen-based damp-proof course (DPC) • K-Dek with TPO membrane, 100 mm thick, R5.00 • K-Dek with PVC membrane, 100 mm thick, R5.00 • Membrane, bentonite • Membrane, bitumen, fibre reinforced • Membrane, building wrap, polyethylene (PE) • Membrane (DPM), polyethylene, underslab, vapour barrier • Membrane, polyvinyl chloride (PVC) • Membrane, synthetic rubber (EPDM)
A1.9 Metals and metal-containing composites	Aluminium • Aluminium, primary (anodised finish, one side 0.02 mm), flat sheet, 0.7 mm BMT • Aluminium, primary (anodised finish, one side 0.02 mm), flat sheet, 0.9 mm BMT • Aluminium, primary (anodised, one side 0.02 mm), profile sheet metal, generic all profiles, 0.7 mm BMT • Aluminium, primary (anodised, one side 0.02 mm), profile sheet metal, generic all profiles, 0.9 mm BMT • Aluminium, primary (anodised finish, one side 0.02 mm), louvre blades, 2.0 mm BMT • Aluminium, primary (no finish), profile sheet metal, 0.7 mm BMT • Aluminium, primary (powder coated finish, one side 0.08 mm), flat sheet, 0.7 mm BMT • Aluminium, primary (powder coated finish, one side 0.08 mm), flat sheet, 0.9 mm BMT • Aluminium, flashing (primary (powder coated, one side 0.08 mm), flat sheet, 0.9 mm BMT Aluminium composite • Aluminium composite material (ACM) panel, 4 mm thick Steel (structural) • Steel (primary), structural, columns and beams • Steel (primary), circular hollow section (different sizes), factory painted • Steel (primary), equal angle (different sizes), factory painted • Steel (primary), parallel flange channel (different sizes), factory painted • Steel (primary), rectangular hollow section (different sizes), factory painted • Steel (primary), square hollow section (different sizes), factory painted • Steel (primary), taper flange beam (different sizes), factory painted • Steel (primary), unequal angle (different sizes), factory painted • Steel (primary), universal beams (different sizes), factory painted • Steel (primary), universal columns (different sizes), factory painted • Steel (primary), circular hollow section (different sizes), unpainted at factory • Steel (primary), equal angle (different sizes), unpainted at factory • Steel (primary), parallel flange channel (different sizes), unpainted at factory • Steel (primary), rectangular hollow section (different sizes), unpainted at factory • Steel (primary), square hollow section (different sizes), unpainted at factory

- Steel (primary), taper flange beam (different sizes), unpainted at factory
- Steel (primary), unequal angle (different sizes), unpainted at factory
- Steel (primary), universal beams (different sizes), unpainted at factory
- Steel (primary), universal columns (different sizes), unpainted at factory

Steel (galvanised) - profiles

- Steel, primary (galvanised finish, both sides, 0.02 mm each, coating class Z275), profile metal sheet, generic all profiles, 0.4mm BMT, exposure zone B
- Steel, primary (galvanised finish, both sides, 0.02 mm each, coating class Z275), profile metal sheet, generic all profiles, 0.4mm BMT, exposure zone C
- Steel, primary (galvanised finish, coating class Z275), cold rolled profile metal sheet, trough section 56mm deep at 305mm ctrs, 0.75 BMT
- Steel, primary (galvanised finish, coating class Z275), cold rolled profile metal sheet, trough section 56mm deep at 305mm ctrs, 0.95 BMT

Steel (galvanised) - purlins

- Purlins, DHS (all profiles), steel, primary (galvanised finish, coating class Z275), generic all profiles, exposure zone B
- Purlins, DHS (all profiles), steel, primary (galvanised finish, coating class Z275), generic all profiles, exposure zone C

Steel (galvanised) – stud walls

- Stud wall system, steel, primary (galvanised finish, 2 sides, 0.02 mm each, coating class Z275), 92.1x33.1 0.55 BMT @ 300ctrs, wall height 4.4-8.8m, 1 nogging row
- Stud wall system, steel, primary (galvanised finish, 2 sides, 0.02 mm each, coating class Z275), 92.1x33.1 0.55 BMT @ 450ctrs, wall height 4.4-8.8m, 1 nogging row
- Stud wall system, steel, primary (galvanised finish, 2 sides, 0.02 mm each, coating class Z275), 150x33.1 0.75 BMT @ 800ctrs, wall height 4.4-8.8m, 1 nogging row

Steel – reinforcement

- Steel, reinforcement, primary, bar

Steel (zinc / aluminium alloy)

- Colorsteel® Endura® 0.4 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B
- Colorsteel® Endura® 0.55 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B
- Colorsteel® Endura® 0.4 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C
- Colorsteel® Endura® 0.55 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C
- Colorsteel® Maxx® 0.4 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B
- Colorsteel® Maxx® 0.55 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B

	• Colorsteel® Maxx® 0.4 mm BMT (primary), AZ200 (200 g/m² ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C • Colorsteel® Maxx® 0.55 mm BMT (primary), AZ200 (200 g/m² ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C • Colorsteel® Maxx® 0.4 mm BMT (primary), AZ200 (200 g/m² ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zones D/E • Colorsteel® Maxx® 0.55 mm BMT (primary), AZ200 (200 g/m² ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone D/E
A1.10 Paint	Exterior • Paint (exterior) water-borne, applied to aluminium (2 coats / m²) • Paint (exterior) water-borne, applied to steel (2 coats / m²) • Paint (exterior), water-borne, for masonry (2 coats / m²) • Paint (exterior), water-borne, for timber (2 coats / m²) • Paint (exterior), water-borne, primer/sealer (1 coat / m²) Interior • Paint, water-borne, walls (Dulux Wash&Wear® low sheen - vivid white) (2 coats / m²) • Paint, water-borne, walls (Dulux Wash&Wear® matt - vivid white) (2 coats / m²) • Paint, water-borne, walls (Dulux Wash&Wear® semi-gloss - vivid white) (2 coats / m²) • Paint, water-borne, walls (Dulux Wash&Wear® gloss - vivid white) (2 coats / m²) • Paint, water-borne, walls (Dulux Wash&Wear® +Plus anti bac low sheen - vivid white) (2 coats / m²) • Paint, water-borne, walls (Dulux Wash&Wear® +Plus kitchen and bathroom semi-gloss - vivid white) (2 coats / m²) • Paint, water-borne, walls (Dulux Wash&Wear® +Plus kitchen and bathroom low sheen - vivid white) (2 coats / m²) • Paint, water-borne, walls (Wash&Wear® +plus super hide low sheen - vivid white) (2 coats / m²) • Paint, water-borne, walls (Wash&Wear® +plus super tough low sheen (parts A&B) - vivid white) (2 coats / m²) • Paint, water-borne, ceilings (Wash&Wear® kitchen & bathroom ceiling flat) (2 coats / m²) • Paint, water-based acrylic primer/undercoat (Dulux acrylic sealer undercoat) (1 coat / m²) • Paint, water-based acrylic primer/undercoat (Dulux professional® total prep) (1 coat / m²)
A1.11 Plasterboard	Specific data • Plasterboard (GIB® standard 10 mm) • Plasterboard (GIB® standard 13 mm) • Plasterboard (GIB wideline® 10 mm) • Plasterboard (GIB wideline® 13 mm) • Plasterboard (GIB aqualine® 10 mm) • Plasterboard (GIB aqualine® 13 mm) • Plasterboard (GIB braceline® GIB noiseline® 10 mm) • Plasterboard (GIB braceline® GIB noiseline® 13 mm) • Plasterboard (GIB ultraline® 10 mm) • Plasterboard (GIB ultraline® 13 mm) • Plasterboard (GIB fyreline® 10 mm) • Plasterboard (GIB fyreline® 13 mm) • Plasterboard (GIB fyreline® 16 mm)

	• Plasterboard (GIB fyreline® 19 mm) • Plasterboard (GIB toughline® 13 mm) • Plasterboard (GIB superline® 13 mm) Generic data • Plasterboard (generic)
A1.12 Services and infrastructure	Vertical transport • Elevator (30 floors) - thyssenkrupp momentum - rated load = 1588 kg, speed = 3.56 m/s • Elevator (12 floors) - thyssenkrupp synergy - rated load = 1588 kg, speed = 1.78 m/s • Elevator (5 floors) - thyssenkrupp evolution - rated load = 1000 kg, speed = 1.0 m/s • Elevator (3 floors) - thyssenkrupp endura machine room-less - rated load = 1134 kg, speed = 0.76 m/s • Elevator (14 floors) - OTIS Gen2 Stream High Rise® - rated load up to 1850 kg, speed up to 2.5 m/s • Elevator (12 floors) - OTIS Gen2 Stream® - rated load up to 2500 kg, speed up to 2.5 m/s • Elevator (5 floors) - OTIS Gen2 Life® - rated load up to 1000 kg, speed up to 1.6 m/s Energy generation • Energy generation, photovoltaic (PV) system (incl. roof mounts), 3kW Water and drainage • PVC-U (unplasticised polyvinylchloride), non-pressure pipes, exterior use • PVC-U (unplasticised polyvinylchloride), non-pressure pipes, interior use
A1.13 Timber and engineered wood	Engineered wood, cross laminated timber (CLT) • Engineered wood, cross laminated timber (CLT) [from sustainable forest management practices] • Engineered wood, cross laminated timber (CLT) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] Engineered wood, glued laminated timber (glulam, softwood) • Engineered wood, glued laminated timber (glulam, softwood) [from sustainable forest management practices] • Engineered wood, glued laminated timber (glulam, softwood) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] Engineered wood, I-joist profile • Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices] • Engineered wood, I-joist profile, 300x63 [from sustainable forest management practices] • Engineered wood, I-joist profile, 300x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 360x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices] • Engineered wood, I-joist profile, 240x46 [from sustainable forest management practices] • Engineered wood, I-joist profile, 240x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 360x63 [from sustainable forest management practices]

	• Engineered wood, I-joist profile, 400x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 300x63 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 300x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 360x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 240x46 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 240x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 360x63 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 400x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] <u>Engineered wood, laminated veneer lumber (LVL)</u> • Engineered wood, laminated veneer lumber (LVL) [from sustainable forest management practices] • Engineered wood, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] <u>Engineered wood, MDF (specific data)</u> • MDF, thick, coated (average thickness 18 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) • MDF, thick, uncoated (average thickness 20 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) • MDF, thin, uncoated (average thickness 3 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) <u>Engineered wood, plywood (exterior, A-bond)</u> • Engineered wood, plywood (exterior, A-bond) [from sustainable forest management practices] • Engineered wood, exterior cladding, plywood (exterior, A-bond) [from sustainable forest management practices] • Engineered wood, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, exterior cladding, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] <u>Engineered wood, post tensioned timber frame structure</u>

	• Post tensioned timber frame structure, laminated veneer lumber (LVL) [from sustainable forest management practices], inc. steel reinforcing • Post tensioned timber frame structure, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], inc. steel reinforcing Timber, softwood • Timber, softwood, dressed kiln-dried sections [from sustainable forest management practices] • Timber, exterior cladding construction, soft wood, dressed kiln-dried sections [from sustainable forest management practices] • Timber wall framing, soft wood, dressed kiln-dried sections [from sustainable forest management practices] • Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from sustainable forest management practices] • Timber, structural framing, soft wood, dressed kiln-dried, interior use [from sustainable forest management practices] • Timber structural framing, soft wood, dressed kiln-dried, exterior use [from sustainable forest management practices] • Timber, softwood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber, exterior cladding construction, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber wall framing, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber, structural framing, soft wood, dressed kiln-dried, interior use [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber structural framing, soft wood, dressed kiln-dried, exterior use [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] Floor (hardwood) • Hardwood (dressed, kiln-dried) floor [from sustainable forest management practices], with galvanised fixings • Hardwood (dressed, kiln-dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings Floor (MDF) • MDF (floor) [from sustainable forest management practices], with galvanised nails (generic) • MDF (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised nails (generic) Floor (particleboard) • Particleboard (floor) [from sustainable forest management practices], with galvanised fixings • Particleboard (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings Floor (plywood)

	• Plywood (A-bond, floor) [from sustainable forest management practices], with galvanised fixings • Plywood (A-bond, floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings Floor (softwood) • Softwood (dressed kiln-dried) floor [from sustainable forest management practices], with galvanised fixings • Softwood (dressed kiln-dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings

A1.1 Aggregates

Category	-
Name	Granular fill
Description	Gravel obtained by blasting and/or excavating which may be crushed and then screened by size.
Platform/source(s) of data	EcoInvent 3.1, adapted
Data characteristics	Based on "Gravel production, crushed", adapted to include use of NZ Grid medium voltage electricity (Sacayon Madrigal, 2015) and combustion of diesel checked to ensure appropriate sulphur content (10 ppm).
Age	Process data varies with dataset – see www.ecoinvent.org.
Technology coverage	Quarried stone is crushed and sorted.
Geographical coverage	NZ for grid electricity. Rest of the World/Global for other datasets.
Assumptions	Fill material derived from a manufactured process requiring crushing. If the source of fill does not require crushing or is from a recycled source, impacts are likely to be less.
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	Calculated greenhouse gas impact of 0.0056 kg CO_2 eq./kg compare to 0.003 kg CO_2 eq./kg for hardfill (Alcorn, 2010) and 0.0052 kg CO_2 eq./kg for general aggregate (Hammond & Jones, 2011).
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	-
Name	Sand
Description	Excavated material that is finer than gravel
Platform/source(s) of data	EcoInvent 3.1, adapted.
Data characteristics	Based on EcoInvent 3.1 dataset "Gravel and sand quarry operation". All electricity flows summed and attributed to NZ medium voltage grid electricity (Sacayon Madrigal, 2015). Sulphur content of diesel checked to meet NZ requirements of 10 ppm. Other flows unadjusted.
Age	Various – see www.ecoinvent.org

Technology coverage	Quarrying of sand to quarry gate.
Geographical coverage	Based on Rest of the World (RoW) dataset in EcoInvent 3.1 (outside Europe). Supporting data are Global except grid electricity (medium voltage), which is New Zealand.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	Data derived based on an allocation between sand and gravel produced at the quarry. See www.ecoinvent.org.
Plausibility check	Comparison with several sources of data (thinkstep and EcoInvent 3.1 databases, and published data for hardfill (Alcorn, 2010; Hammond & Jones, 2011) show a greenhouse gas impact in the range 0.002–0.005 kg CO_2 eq/kg sand. Adapted dataset is within this range being 0.0027 kg CO_2 eq/kg sand).
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	-
Name	Clay fill
Description	Clay removal operation.
Platform/source(s) of data	EcoInvent 3.1 Density from ASHRAE (2009)
Data characteristics	Based on "Clay pit operation".
Age	Process data varies with dataset – see www.ecoinvent.org.
Technology coverage	Excavation by digger, transport and grinding
Geographical coverage	Rest of the World/Global.
Assumptions	Assumes most clay is imported. Therefore, data not adapted for New Zealand.
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	See www.ecoinvent.org

A1.2 Clay (fired)

Category	-
Name	Brick (clay)
Description	Production of brick
Platform/source(s) of data	EcoInvent 3.3, supplied by lifecycles using NZ grid electricity (Sacayon Madrigal, 2015).
Data characteristics	See www.ecoinvent.org.
Age	See www.ecoinvent.org for EcoInvent data. NZ grid electricity model based on grid average data for 2015–2017.
Technology coverage	Includes grinding, mixing, storage, forming (using an extruding moulding method), cutting, drying, firing, loading and packing.
Geographical coverage	Supporting EcoInvent data from Global. Grid electricity data for New Zealand (Sacayon Madrigal, 2015).

Assumptions	See www.ecoinvent.org.
Completeness/ exclusions	Based on EcoInvent.
Plausibility check	Greenhouse gas results are 0.27 kg CO_2 e/kg. For comparison purposes, Alcorn (2010) calculated a value of 0.19 kg CO_2 eq./kg and the ICE database provides values in the range 0.23–0.24 kg CO_2 eq./kg (Hammond and Jones, 2011). Heluz (2015) published an EPD for its range of hollow bricks manufactured in Europe. This shows embodied greenhouse gas results of 0.179 to 0.354 kg CO_2 eq./kg, depending on the specific brick product considered. Another European EPD (Bauen mit Backstein Zweischalige Wand Marketing e.V., 2016) provides a value of 0.256 kg CO_2 eq./kg. for facing bricks, clay pavers and brick slips. The results represent 12 member companies constituting 90% of the Zweischalige Wand association and 95% of production volume from participating companies in Germany.
Consistency e.g. with EN 15804	Based on EcoInvent.

Category	-
Name	Tile (ceramic)
Description	Manufacture of ceramic tiles
Platform/source(s) of data	NG Kutahya Seramik, 2015
Data characteristics	Represents manufacture at the plant in Turkey. Outputs of the plant are distributed worldwide.
Age	Manufacture of floor tiles in 2013–2014.
Technology coverage	Represents manufacture of ceramic tiles based on primarily kaolin and ball clay. These are mixed with mineral modifiers such as quartz and feldspar. Includes raw material acquisition, milling and spraying, pressing, drying, glaze preparation, glazing, firing and packaging. The process uses natural gas and electricity.
Geographical coverage	Manufacture in Turkey.
Assumptions	NG Kutahya Seramik, 2015
Completeness/ exclusions	NG Kutahya Seramik, 2015
Plausibility check	Greenhouse gas results are 0.53 kg CO_2 eq./kg. For comparison purposes, the ICE database provides values in the range 0.74–0.78 kg CO_2 eq./kg (Hammond and Jones, 2011). Figures based on an adapted version of EcoInvent 3.3, assuming manufacture with NZ grid electricity (supplied by lifecycles), provides a figure of 0.5 kg CO_2 eq./kg.
Consistency e.g. with EN 15804	EPD is EN 15804 compliant.

Category	Sanitary ware
Name	Sanitary ware (vitreous china)
Description	Manufacture of vitreous china sanitaryware e.g. lavatories, washbasins, bidets, bathtubs, shower trays.

Platform/source(s) of data	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018
Data characteristics	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018
Age	Data based on 2016 manufacture.
Technology coverage	Includes raw material supply and transport, and manufacturing (including mould preparation, slip casting, drying, glaze preparation, glazing and firing).
Geographical coverage	Manufacture in Turkey. Scope of EPD is global, as the product is shipped worldwide.
Assumptions	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018. Assume this product is imported to New Zealand.
Completeness/ exclusions	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018. Excludes sanitaryware furniture such as taps, toilet seat and lid etc.
Plausibility check	Greenhouse gas results are reported for an 18 kg toilet and a 9 kg wash hand basin. The greenhouse gas impact per kg is 0.978 kg CO_2 eq and is scalable to the size of the sanitaryware (within limits). For comparison purposes, other data sources provide the following values: • 1.9 kg CO_2 eq./kg (Matel Hammadde Sanayi ve Ticaret A.S., 2015) • 0.854 kg CO_2 eq./kg (Canakcilar Seramik Sanayi ve Ticaret A.S., 2014b) • 1.208 kg CO_2 eq./kg (Ideal Seramik Sihhi Tesisat Malz. San. ve Tic. A.S., 2014b) • 1.51–1.61 kg CO_2 eq./kg for sanitary products (Hammond and Jones, 2011)
Consistency e.g. with EN 15804	The EPD is compliant with EN 15804.

Category	Sanitary ware
Name	Ceramic basin sanitary ware (ceramic fine fire clay) (basin - mass = 9 kg) WC, sanitary ware (ceramic fine fire clay) (toilet - mass = 18 kg)
Description	Manufacture of fine fire clay sanitaryware e.g. lavatories, washbasins, bidets, bathtubs, shower trays.
Platform/source(s) of data	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018
Data characteristics	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018
Age	Data based on 2016 manufacture.
Technology coverage	Includes raw material supply and transport, and manufacturing (including mould preparation, slip casting, drying, glaze preparation, glazing and firing).
Geographical coverage	Manufacture in Turkey. Scope of EPD is global, as the product is shipped worldwide.
Assumptions	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018. Assume this product is imported to New Zealand.
Completeness/ exclusions	Kaleseramik Canakkale Kalebodur Seramik Sanayi A.S., 2018. Excludes sanitaryware furniture such as taps, toilet seat and lid etc.
Plausibility check	Greenhouse gas results are reported for an 18 kg toilet and a 9 kg wash hand basin. The greenhouse gas impact per kg is 1.075 kg CO_2 eq and is scalable to the size of the sanitaryware (within limits).

	For comparison purposes, other data sources provide the following values: • 0.97 kg CO_2eq./kg (Canakcilar Seramik Sanayi ve Ticaret A.S., 2014a) • 1.372 kg CO_2eq./kg (Ideal Seramik Sihhi Tesisat Malz. San. ve Tic. A.S., 2014a) • 1.51 – 1.61 kg CO_2eq./kg for sanitary products (Hammond and Jones, 2011)
Consistency e.g. with EN 15804	The EPD is compliant with EN 15804.

A1.3 Concrete

Category	Autoclaved aerated concrete
Name	Autoclaved aerated concrete (AAC) blocks Autoclaved aerated concrete (AAC), precast block, density 525kg/m^3, exc. steel reinforcing Autoclaved aerated concrete (AAC), precast block, density 650kg/m^3, exc. steel reinforcing
Description	AAC is a lightweight, precast concrete with a cellular or foam structure.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Adapted from dataset "Aerated autoclaved concrete block production", including addition of medium voltage NZ grid electricity (Sacayon Madrigal, 2015).
Age	See www.ecoinvent.org
Technology coverage	Raw materials (sand/gravel, quicklime, anhydrite, cement and aluminium powder) are mixed with water and poured into a mould. From the resulting reaction, hydrogen is released producing pores with a diameter of 2–3 mm. Includes the raw materials, their transport to the finishing plant, the energy for the autoclaving process, the packaging, the infrastructure and the disposal of wastewater and some solid household (e.g. packing material) waste
Geographical coverage	Three suppliers of AAC blocks in New Zealand, two of which manufacture in New Zealand and the third importing from Australia. Base data adapted for New Zealand. Electricity use divided two-thirds NZ grid electricity (Sacayon Madrigal, 2015) and one-third Australia grid electricity, in the absence of market share information. Production of sand and diesel combustion data adapted for New Zealand. All other data – Rest of the World (RoW) in EcoInvent (outside Europe).
Assumptions	Hardening is assumed to be by air-drying. The lifespan of the plant is assumed to be 50 years.
Completeness/ exclusions	Density of manufactured product not provided but assumed to be 445 kg/m^3 based on similar product. Lifting of blocks onto transport and any packaging or pallets used not separately modelled, so assumed this is included within the data.
Plausibility check	Modelled results compared to other data sources, these being the thinkstep and EcoInvent 3.1 databases, the ICE database (Hammond and Jones, 2011) and published EPDs (Turk Ytong Sanayi A.S., 2015; Xella Baustoffe GmbH, 2012).

	Results show good agreement with thinkstep and EcoInvent 3.1 databases, but are higher than reported in the ICE database (0.24–0.375 kg CO_2 eq./kg compared to 0.51 kg CO_2 eq./kg). Modelled results also show reasonable comparison with reviewed EPDs for most indicators.
Consistency e.g. with EN 15804	Based on EcoInvent.

Category	Concrete, block (masonry wall)
Name	Concrete blocks, 17.5 MPa Masonry wall, incl. concrete block 15 series (17.5 MPa OPC), grouted 22 MPa (OPC), inc. steel reinforcing Masonry wall, incl. concrete block 20 series (17.5 MPa OPC), grouted 22 MPa (OPC), inc. steel reinforcing Masonry wall, incl. concrete block 25 series (17.5 MPa OPC), grouted 22 MPa (OPC), inc. steel reinforcing
Description	Hollow concrete block walls consist of hollow concrete blocks, a grout infill and steel reinforcement. Quantity of steel reinforcement based on NZS 4229:2013 *Concrete masonry buildings not requiring specific engineering design*.
Platform/source(s) of data	EcoInvent 3.1, adapted
Data characteristics	Based on "Concrete block production", adapted to include use of medium voltage NZ grid electricity (Sacayon Madrigal, 2015). Steel reinforcement manufacture uses EcoInvent 3.1 data.
Age	See www.ecoinvent.org.
Technology coverage	Ready mixed concrete is poured into a mould, after which it is air dried and then packed ready for transport. The concrete blockwork wall comprises hollow concrete blocks with reinforcement with grout poured to fill voids.
Geographical coverage	Concrete mix designs based on Allied Concrete data. Reinforcement based on EcoInvent data, adapted to include use of New Zealand grid electricity. Supporting EcoInvent data from "Rest of the World (RoW)" (outside Europe).
Assumptions	Original EcoInvent data implies use of 50 MPa concrete (0.00042 m^3 needed to make 1 kg blocks = density of 2380 kg/m^3 = 50 MPa. To produce a hollow concrete block wall with a strength of 12 MPa, a 17.5 MPa ready mix concrete is used to make blocks and included with 22 MPa grout infill (with reinforcing). This is consistent with Section 3.1 of the NZ Concrete Masonry Manual (New Zealand concrete), which is drawn from NZS 4230:2004 *Design of reinforced concrete masonry structures*. Therefore, the volume of concrete to make 1 kg blocks in the original EcoInvent dataset was adjusted according to the density of 17.5 MPa concrete = 0.0004273 m^3 (using the density of 17.5 MPa ready mixed concrete). Another assumption is that the ready mixed concrete is made at the same site as production of blocks so no additional transport of concrete to the block yard is considered. Concrete wastage is per data embedded in Allied Concrete data, and no subsequent wastage of blocks before shipment is assumed.

	Grout data based on 20 MPa ready mixed concrete using mix design provided by Allied Concrete. Grout has an absence of coarse aggregate and use of a higher proportion of fine aggregate, therefore use of data for in situ concrete is an approximation. For 12 MPa infilled blocks, grout with a compressive strength of 22 MPa is used in combination with concrete blocks of 17.5 MPa (New Zealand concrete Masonry).
Completeness/ exclusions	Infrastructure required for block manufacture, other than that associated with ready mixed concrete production. Lifting of the product onto trucks for despatch, any packaging or use of pallets assumed to be included in the original EcoInvent dataset on which the data are based. Mortar in joints between concrete blocks excluded.
Plausibility check	Greenhouse gas results are around 0.13 kg CO_2 eq./kg (regardless of series) for reinforced and grouted concrete blockwork. For comparison purposes, Alcorn (2010) reports 0.112 kg CO_2 /kg for concrete block only. Data in EcoInvent show higher greenhouse gas values than calculated here but appear to be made from higher compressive strength concrete.
Consistency e.g. with EN 15804	Based on EcoInvent.

Category	Concrete, in-situ (made with OPC), unreinforced and reinforced
Name	Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC) at 17.5, 20, 25, 30, 35, 40, 45 and 50 MPa compressive strengths *Separate materials for all variations of compressive strengths (17.5 MPa, 20, 25, 30, 35, 40, 45, and 50 MPa) and reinforcing steel quantities (50 kg/m³, 100, 150, and 200 kg/m³).* *Example materials:* *Concrete, 17.5 MPa, in-situ, no reinforcement, (OPC)* *Concrete, 20.0 MPa, in-situ, no reinforcement, (OPC)* Reinforced concrete (25, 30, 35, 40, 45 and 50 MPa), composite floor decking, trapezoidal deck section 75 mm and 95 mm deep troughs at 300 mm ctrs, in-situ slab (at 125, 130, 140, 150, 160, 170, 180 and 200 mm thicknesses), inc. 100 and 150 kg/m³ steel reinforcing, OPC *Variations for in-situ slab strength (25, 30, 35, 40, 45, and 50 MPa) slab thickness (125, 130, 140 mm etc), deck sections size (75, 95 mm), and reinforcement content (100, 150 kg/m³).*
Description	Represents reinforced concrete made with pump and standard grades of Normal ready mixed concrete (as defined in NZS 3104:2003 *Specification for concrete production*) reaching age at 28 days, with reinforcement.
Platform/source of data	Allied Concrete, EcoInvent 3.1, AusLCI, Pacific Steel EPD (Pacific Steel, 2018)
Data characteristics	Concrete mixes based on data provided by Allied Concrete. Ordinary Portland cement production based on AusLCI data (http://alcas.asn.au/AusLCI/) for manufacture of cement using a dry process. Other processes use EcoInvent 3.1 data including: Gravel production, crushed (adapted with NZ electricity). Sand quarry operation (adapted with NZ electricity). Tap water production, conventional treatment.

	Data for admixtures based on indicators reported in an EPD for water resisting admixtures (European Federation of Concrete Admixtures Associations Ltd). Data for reinforcement, as reported by Pacific Steel (2018). Medium voltage New Zealand grid electricity (Sacayon Madrigal, 2015).
Age	2013 data for mix designs. Process data varies with dataset – see www.ecoinvent.org (and AusLCI for cement data).
Technology coverage	Covers batching plant operations (central mix and dry batch) at 28 sites in the North and South Islands of New Zealand. Includes cement, aggregate, sand and admixture production and transport to the batching plants, plus delivery of water for use in concrete mixes and for washing trucks etc. Use of electricity and diesel at the batching plants is included, as is transport and disposal of generated wastes. Data for reinforcement based on processes reported by Pacific Steel (2018). Reinforcement amounts are based on typical values that may be used in engineering practice, up to approximately 2% by volume (based on estimates from BRANZ structural engineers).
Geographical coverage	Mix designs and batching plant operations based on New Zealand data (provided by Allied Concrete). Grid electricity (medium voltage) based on the New Zealand grid. Supporting data uses Rest of the World (RoW) data in EcoInvent 3.1 i.e. outside Europe.
Assumptions	All water obtained from the reticulated network. In practice, batching plants also collect rainwater which is not considered. A generic concrete model is used, which additionally allows calculation of impacts for concretes with cement replacement materials such as ground granulated blast furnace slag (GGBS) and pulverised fly ash (PFA). It is assumed that half of the cement is imported (travelling a one way distance of 5000 km) and half is produced domestically.
Completeness/ exclusions	Return truck journeys for materials brought to the batching plant. Any packaging associated with materials brought to the batching plant. A1–A3 data are calculated for reinforced concrete with reinforcement, even though these are not physically combined until at the construction site (in module A5). Indicators calculated based on the mass of concrete and steel per cubic metre of reinforced concrete, normalised to 1 kg of reinforced concrete.
Plausibility check	Ready mixed concrete Calculated greenhouse gas results for ready mixed concrete in comparison with figures cited in the ICE database (Hammond and Jones, 2011) for the UK are summarised below:

Compressive strength (MPa)	Modelled (kg CO_2 eq./kg)	ICE database (kg CO_2 eq./kg)
17.5	0.109	0.123
20	0.113	0.123–0.132
25	0.123	0.132–0.14
30	0.133	0.14–0.148
35	0.149	0.148–0.163
40	0.172	0.163–0.188
45	0.181	0.188
50	0.203	0.188

Differences are likely to arise from the amount of cement in each mix and the source(s) of cement.

Alcorn (2010) reports 0.118 and 0.164 kg CO_2 eq./kg for 17.5 and 30 MPa compressive strengths respectively.

Steel reinforcement

Concrete may contain steel reinforcing bar (rebar) or steel mesh which is used to resist tensile or shear forces (Cement & Concrete Association of New Zealand, 2010). Amounts of reinforcement present in concrete varies depending on the reinforced concrete application, such as floor slabs, beams, columns or walls, with minimum amounts based on NZS 3101.1&2:2006 *Concrete structures standard*. Results have been calculated based on a steel content of 50, 100, 150 and 200 kg/m^3 reinforced concrete.

Data used is declared in Pacific Steel (2018) in the "bar" column. Nebel, Alcorn and Wittstock (2011) report 0.45 kg CO_2 eq./kg for steel reinforcing made using electric arc furnaces based primarily on a scrap steel input. Pacific Steel (2018) reports 3.97 kg CO_2 eq./kg based on primary production of reinforcement.

Results per kg with different levels of reinforcing are provided in modules A1–A3 (even though for in-situ concrete applications, the reinforcing is added to the concrete at the construction site).

Reinforced concrete

Calculated greenhouse gas results for reinforced concrete (reinforcement at 100 kg/m^3) in comparison with figures from Berg et al. (2016) and the ICE database (Hammond and Jones, 2011) for the UK are summarised below:

Compressive strength (MPa)	Database v9.1 figures (kg CO_2 eq./kg)	Original figures (Berg et al., 2016) (kg CO_2 eq./kg)	ICE database (kg CO_2 eq./kg)
17.5	0.27	0.2	0.2
20	0.27	0.2	0.2–0.209
25	0.28	0.21	0.209–0.217
30	0.29	0.22	0.217–0.225
35	0.31	0.24	0.225–0.24
40	0.33	0.26	0.24–0.265
45	0.34	0.27	0.265
50	0.36	0.29	0.265

Results are now higher in the updated v9.1 data, in comparison with the original figures provided in Berg et al. (2016) and figures cited in the ICE database. This is primarily due to the increased values reported for reinforcement.

Consistency e.g. with EN 15804	See www.ecoinvent.org.

Category	Concrete, in-situ (made with secondary cementitious material), unreinforced and reinforced
Name	Unreinforced and reinforced in-situ concrete with secondary cementitious replacements at 17.5, 20, 25, 30, 35, 40, 45 and 50 MPa compressive strengths

	Separate materials for all variations of compressive strengths (17.5 MPa, 20, 25, 30, 35, 40, 45, and 50 MPa), reinforcing steel quantities (50, 100, 150, and 200 kg/m^3), and for secondary cementitious replacements (25%, 50%, and 75% GGBS, and 20% and 35% PFA). *Examples:* *Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m^3 steel reinforcing, (25% GGBS)* *Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m^3 steel reinforcing, (50% GGBS)* *Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m^3 steel reinforcing, (75% GGBS)* *Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m^3 steel reinforcing, (20% PFA)* *Reinforced concrete, 17.5 MPa, in-situ, inc. 50 kg/m^3 steel reinforcing, (35% PFA)* Reinforced concrete (25, 30, 35, 40, 45 and 50 MPa), composite floor decking, trapezoidal deck section 75 mm and 95 mm deep troughs at 300 mm ctrs, in-situ slab (at 125, 130, 140, 150, 160, 170, 180 and 200 mm thicknesses), inc. 100 and 150 kg/m^3 steel reinforcing, with secondary cementitious replacements
Description	Represents reinforced concrete made with pump and standard grades of ready mixed concrete comprising supplementary cementitious material (SCM) as a direct replacement for cement plus reinforcement. The replacement level of SCM defined in section 4.1.2 of NZS 3122:2009 *Specification for Portland and blended cements (general and special purpose)* for blended cements are as follows. Fly ash or pozzolan: >10–35%. Ground granulated blast furnace slag: >10–75%. Amorphous silica: up to 10%.
Platform/source of data	Allied Concrete/EcoInvent 3.1/AusLCI/Pacific Steel (2018)
Data characteristics	Original mixes based on Allied Concrete data. GGBS substitutes 25%, 50% and 75% of cement. PFA substitutes 20% and 35% cement. Reinforcement content based on BRANZ structural engineer estimates for typical and maximum quantities. Processes use EcoInvent 3.1 and AusLCI data.
Age	2013 data for mix designs. Reinforcement data per Pacific Steel (2018). Process data varies with dataset – see www.ecoinvent.org.
Technology coverage	GGBS is a product of blast furnace slag made at steel plants. Data are based on AusLCI http://alcas.asn.au/AusLCI/. Fly ash is obtained as a result of cleaning of flue gas at large coal fired power plants. Data are also based on AusLCI http://alcas.asn.au/AusLCI/. Both products are assumed to be imported to New Zealand and are transported 10,000 km by ship and 50 km by truck (one way). For production of concrete and reinforcement, see *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Geographical coverage	Concrete mix design data from New Zealand. Reinforcement data based on EcoInvent, adapted to reflect use of New Zealand grid electricity. GGBS and PFA data from Australia.

<table>
<tr><td>Assumptions</td><td>GGBS and PFA assumed to replace cement on a 1:1 basis. No other changes to the concrete are taken into account.
In a worldsteel report (worldsteel, 2014), 1 tonne of GGBS typically replaces 0.9–1 tonne of cement.</td></tr>
<tr><td>Completeness/ exclusions</td><td>Return truck journeys.
Any packaging materials.</td></tr>
<tr><td>Plausibility check</td><td>Calculated greenhouse gas results (without reinforcement) in comparison with figures cited in the ICE database (Hammond and Jones, 2011) for the UK are summarised below. The percentage figures refer to cement replacement by PFA and all results are in kg CO2 eq./kg:

<table>
<tr><th>Compressive strength (MPa)</th><th>Model (20%)</th><th>ICE database (15%)</th><th>Model (35%)</th><th>ICE database (30%)</th></tr>
<tr><td>17.5</td><td>0.092</td><td>0.112</td><td>0.078</td><td>0.1</td></tr>
<tr><td>20</td><td>0.095</td><td>0.112–0.122</td><td>0.081</td><td>0.1–0.108</td></tr>
<tr><td>25</td><td>0.103</td><td>0.122–0.13</td><td>0.088</td><td>0.108–0.115</td></tr>
<tr><td>30</td><td>0.111</td><td>0.13–0.138</td><td>0.095</td><td>0.115–0.124</td></tr>
<tr><td>35</td><td>0.124</td><td>0.138–0.152</td><td>0.106</td><td>0.124–0.136</td></tr>
<tr><td>40</td><td>0.144</td><td>0.152–0.174</td><td>0.122</td><td>0.136–0.155</td></tr>
<tr><td>45</td><td>0.151</td><td>0.174</td><td>0.128</td><td>0.155</td></tr>
<tr><td>50</td><td>0.169</td><td>0.174</td><td>0.144</td><td>0.155</td></tr>
</table>

Calculated greenhouse gas results for 25% and 50% cement replacement by GGBS are provided below, for comparison with figures cited in the ICE database (Hammond and Jones, 2011) for the UK. The percentage figures refer to cement replacement by GGBS and all results are in kg CO2 eq./kg:

<table>
<tr><th>Compressive strength (MPa)</th><th>Model (25%)</th><th>ICE database (25%)</th><th>Model (50%)</th><th>ICE database (50%)</th></tr>
<tr><td>17.5</td><td>0.089</td><td>0.096</td><td>0.07</td><td>0.07</td></tr>
<tr><td>20</td><td>0.092</td><td>0.096–0.104</td><td>0.072</td><td>0.07–0.077</td></tr>
<tr><td>25</td><td>0.101</td><td>0.104–0.111</td><td>0.078</td><td>0.077–0.081</td></tr>
<tr><td>30</td><td>0.109</td><td>0.111–0.119</td><td>0.084</td><td>0.081–0.088</td></tr>
<tr><td>35</td><td>0.121</td><td>0.119–0.133</td><td>0.094</td><td>0.088–0.1</td></tr>
<tr><td>40</td><td>0.140</td><td>0.133–0.153</td><td>0.108</td><td>0.1–0.115</td></tr>
<tr><td>45</td><td>0.148</td><td>0.153</td><td>0.114</td><td>0.115</td></tr>
<tr><td>50</td><td>0.165</td><td>0.153</td><td>0.127</td><td>0.115</td></tr>
</table>

PFA results do not match in terms of level of substitution for cement and are consistently lower than results presented in the ICE database. The magnitude of difference decreases with increasing compressive strength.
Comparison of ground granulated blast furnace slag data shows good agreement.</td></tr>
<tr><td>Consistency e.g. with EN 15804</td><td>AusLCI data used for GGBS and PFA for consistency. GGBS data are based on economic allocation.
Alternatively, worldsteel has published EN 15804-compliant data for blast furnace slag production, which only includes an estimate for granulating. In these data, the steel making process, and resulting</td></tr>
</table>

	impacts, are allocated to blast furnace slag based on physical partitioning (worldsteel, 2014).

Category	Concrete, precast, reinforced
Name	Reinforced precast concrete made with ordinary Portland cement (OPC) at 30 MPa and 45 MPa compressive strengths Reinforced precast concrete made with secondary cementitious replacements at 30 MPa and 45 MPa compressive strengths *Separate materials for 30 MPa and 45 MPa compressive strengths, reinforcing steel quantities (50, 100, 150, and 200 kg/m^3), and for secondary cementitious replacements (25%, 50%, and 75% GGBS, and 20% and 35% PFA).* *Example:* *Reinforced concrete, 30 MPa, precast, inc. 50 kg/m^3 steel reinforcing, (25% GGBS).*
Description	Precast concrete may be made away from the construction site or may be made at the construction site as "tilt slab"), by pouring ready mixed concrete into forms where it is left to cure. In-situ concrete of compressive strengths 30 MPa or 45 MPa is typically used with steel reinforcement (Beattie, 2007). These data assume that precast elements are made off site.
Platform/source(s) of data	Based on *Concrete 30 MPa, in situ* and *Concrete 45 MPa, in situ.* Variants using supplementary cementitious materials (SCMs) based on *Concrete (blended – 20% PFA) in situ, Concrete (blended – 35% PFA) in situ, Concrete (blended – 25% GGBS) in situ, Concrete (blended – 50% GGBS) in situ* and *Concrete (blended – 75% GGBS) in situ* for 30 MPa and 45 MPa compressive strengths. Includes lifting of the precast elements from forms onto trucks for transport (see section A.2 on lifting for approach).
Data characteristics	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Age	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Technology coverage	Based on off-site production, with subsequent transport to the construction site (not included here).
Geographical coverage	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Assumptions	Based on 30 MPa or 45 MPa ready mixed concrete.
Completeness/ exclusions	Plant and infrastructure for precasting yard including the forms into which ready mixed concrete is poured. Use of consumables and energy, beyond that associated with production of ready mixed concrete.
Plausibility check	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Consistency e.g. with EN 15804	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*

Category	Concrete, precast, reinforced (double tee)
Name	Reinforced concrete, 45 MPa, precast double-tee, inc. 200 kg/m^3 steel reinforcing (200, 250, 300, 350, 400, 450, 500, 550, 600 series), OPC

	Reinforced concrete, 45 MPa, precast double-tee, inc. 200 kg/m^3 steel reinforcing (200, 250, 300, 350, 400, 450, 500, 550, 600 series), with secondary cementitious replacements *Separate materials for all variations of OPC and secondary cementitious replacements (25%, 50%, and 75% GGBS, and 20% and 35% PFA), and for the different unit series sizes (200, 250, 300, 350, 400, 450, 500, 550, and 600 series).* *Example:* *Reinforced concrete, 45 MPa, precast double-tee, inc. 200 kg/m^3 steel reinforcing, 200 series, (25% GGBS)*
Description	Double tees are a precast prestressed concrete flooring system that is frequently used as an upper floor system and has the advantage of being capable of providing wide spans. They come in different sizes (for example, 200, 250, 300, 400, 450, 500, 550, and 600 mm tee sizes), with each double tee unit consisting of a horizontal flange and two vertical webs so that, in profile, they look like two capital "Ts" (thus giving them their name). Usually, a minimum of a 50 mm layer of reinforced 25 MPa in-situ concrete is poured over the top of a double tee system to provide the floor.
Platform/source(s) of data	Based on *Reinforced in-situ concrete (45 MPa).* For options using supplementary cementitious material (SCMs) of ground granulated blast furnace slag (GGBS) or pulverised fly ash (PFA), see *Reinforced in-situ poured concrete with secondary cementitious replacements.*
Data characteristics	Uses same data as for *Concrete 45 MPa, Precast* (with a steel content of 200 kg/m^3).
Age	Varies with dataset – see www.ecoinvent.org
Technology coverage	Steel strands are prestressed and steel stirrups placed in a form which is filled with 45 MPa in-situ concrete and left to cure. Once installed, a layer of reinforced concrete is added. The thickness of this layer can vary but is a minimum of 50 mm and is 25 MPa (from Stresscrete product information[19]). This is not included in the data for Double Tees but can be added using the *Concrete in situ* data.
Geographical coverage	Rest of the World (RoW) being outside Europe i.e. not New Zealand specific.
Assumptions	Made with 45 MPa in-situ concrete (from Stahlton product data sheet).[20] From calculation (based on Stahlton product data sheet), double tees contain approximately 200 kg/m^3 steel. All indicators provided with this steel content. Includes energy required to lift double tees. We assume a lift of 6 m using a diesel powered crane.
Completeness/ exclusions	Infrastructure associated with double tee production.
Plausibility check	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Consistency e.g. with EN 15804	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*

Category	Concrete, precast, reinforced (hollow core)

[19] www.stresscrete.co.nz
[20] www.stahlton.co.nz

Name	Reinforced concrete, 50 MPa, precast hollow core, inc. 50 kg/m^3 steel reinforcing (200, 300, 400 series), OPC Reinforced concrete, 50 MPa, precast hollow core, inc. 50 kg/m^3 steel reinforcing (200, 300, 400 series), with secondary cementitious replacements *Separate materials for all variations of OPC and secondary cementitious replacements (25%, 50%, and 75% GGBS, and 20% and 35% PFA), and for the different unit series sizes (200, 300 and 400 series).* *Example:* *Reinforced concrete, 50 MPa, precast hollow core, inc. 50 kg/m^3 steel reinforcing, 200 series, (25% GGBS)*
Description	Hollow core is a reinforced, precast concrete profile that is extruded then cut to length. It typically comes in 1200 mm widths and a range of thicknesses (for example, 200, 300 and 400 mm). It is used as a flooring system in commercial buildings.
Platform/source(s) of data	Based on reinforced in-situ concrete (50 MPa). For options using SCMs of ground granulated blast furnace slag (GGBS) or pulverised fly ash (PFA), see *Unreinforced and reinforced in-situ concrete with secondary cementitious replacements at 17.5, 20, 25, 30, 35, 40, 45 and 50 MPa compressive strengths.* Includes lifting of the precast elements from forms onto trucks for transport.
Data characteristics	Calculated based on quantities of 50 MPa concrete and reinforcement.
Age	Varies with dataset – see www.ecoinvent.org
Technology coverage	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC)* and *Unreinforced and reinforced in-situ concrete with secondary cementitious replacements at 17.5, 20, 25, 30, 35, 40, 45 and 50 MPa compressive strengths*
Geographical coverage	Rest of the World (RoW) being outside Europe i.e. not New Zealand specific.
Assumptions	Includes energy required to lift. We assume a lift of 6 m using a diesel powered crane.
Completeness/ exclusions	Infrastructure associated with hollow core production.
Plausibility check	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Consistency e.g. with EN 15804	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*

Category	Concrete (tiles)
Name	Roof tiles, concrete
Description	Production of concrete roof tiles
Platform/source(s) of data	EcoInvent 3.1, adapted.
Data characteristics	Based on "Concrete roof tile production", adapted to include use of NZ medium voltage grid electricity (Sacayon Madrigal, 2015).
Age	See www.ecoinvent.org for EcoInvent data. NZ grid electricity from 2013 data (Sacayon Madrigal, 2015).

Technology coverage	Concrete roof tiles produced by pouring normal concrete into a mould, air drying and packing. Some transport and infrastructure included (from EcoInvent).
Geographical coverage	Supporting EcoInvent data from "Rest of the World (RoW)" (outside Europe). Grid electricity data for New Zealand (Sacayon Madrigal, 2015).
Assumptions	Concrete roof tile manufacturing data based on use of New Zealand grid electricity. Density calculated based on a 438 mm x 330 mm x 27 mm tile weighing 5 kg (from Monier Product Technical Statement for Georgian concrete tiles).
Completeness/ exclusions	Lifting of the product onto trucks for despatch, any packaging or use of pallets assumed to be included in the original EcoInvent dataset on which the data are based.
Plausibility check	Greenhouse gas results are around 0.26 kg CO_2 eq./kg. For comparison purposes, EPDs report 0.114 kg CO_2 eq./kg (Eternit N.V., 2016), 0.254 kg CO_2 eq./kg (Eternit Osterreich GmbH, 2016) and 0.209 kg CO_2 eq./kg (Dachziegelwerke Nelskamp GmbH, 2016). All of these represent European manufacture. EcoInvent data provide higher values.
Consistency e.g. with EN 15804	Based on EcoInvent.

Category	Grout
Name	Grout, masonry infill, 22 MPa
Description	Production of grout
Platform/source(s) of data	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Data characteristics	Unreinforced in-situ 20 MPa concrete used as a proxy.
Age	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Technology coverage	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Geographical coverage	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Assumptions	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Completeness/ exclusions	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Plausibility check	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*
Consistency e.g. with EN 15804	See *Unreinforced and reinforced in-situ concrete, with ordinary Portland cement (OPC).*

Category	Mortar
Name	Mortar
Description	Production of dry powdered mortar
Platform/source(s) of data	EcoInvent 3.1, using ratio of cement, lime and sand for M3 (exterior/inland) per Table 2.1 of NZS 4210:2001 *Masonry construction: Materials and workmanship*.

Data characteristics	EcoInvent dataset called "cement mortar production" adapted for cement : lime : sand content in NZS 4210:2001. Medium voltage NZ grid electricity (Sacayon Madrigal, 2015).
Age	See www.ecoinvent.org for EcoInvent data. NZ grid electricity model based on grid average data for 2015–2017.
Technology coverage	Raw materials mixed and packed. Ratio of raw materials is 1 part cement, 0.5 parts lime (hydrated) and 4 parts sand (by volume). This equates to 0.21 kg, 0.03 kg and 0.76 kg per kg of packed, powdered, dry mortar mix.
Geographical coverage	Supporting EcoInvent data from "Rest of the World (RoW)" (outside Europe) or "Global". Grid electricity data for New Zealand.
Assumptions	Mortar manufacturing data based on use of New Zealand grid electricity (medium voltage). Density of final, cured product is 2000 kg/m^3 (from product literature).
Completeness/ exclusions	Based on EcoInvent.
Plausibility check	Greenhouse gas results are 0.323 kg CO_2 e/kg. For comparison purposes, the ICE database (Hammond and Jones, 2011) provides values in the range 0.14–0.22 kg CO_2 e/kg. Unadjusted EcoInvent data are closer to the calculated figure above.
Consistency e.g. with EN 15804	Based on EcoInvent.

Category	Plaster
Name	Plaster, Cement
Description	Cementitious plasters contain cement and sand. Many are mixed on site.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Rest of World data for base plaster production.
Age	Various – see www.ecoinvent.org
Technology coverage	Includes all manufacturing required to make cementitious plaster, including infrastructure.
Geographical coverage	Rest of the World (outside Europe).
Assumptions	Calculated indicators are for a dry plaster mix which is subsequently combined with water at the construction site in the ratio 6 parts plaster to 1 part water (assuming use of good quality sand, according to NZS 4251.1:2001 *Solid plastering – Cement plasters for walls, ceilings and soffits*). Therefore the dry plaster contributes 0.857 kg per kg of wet plaster.
Completeness/ exclusions	See Technology coverage. Does not include packaging (or addition of water, which happens at the construction site in module A5).
Plausibility check	The ICE database (Hammond and Jones, 2011) reports embodied carbon of 0.13 kg CO_2 eq./kg, noting a wide range of values. The figure calculated for this work is 0.27 kg CO_2 eq./kg, considerably higher. Calculated total primary energy in this work of 1.84 MJ/kg are comparable with the figure cited in the ICE database

Consistency e.g. with EN 15804	See www.ecoinvent.org

A1.4 Fibre cement

Category	-
Name	• Cladding, James Hardie HardieFlex™ (fibre cement, 6.0 mm thickness) • Cladding, James Hardie HardieFlex™ (fibre cement, 7.5 mm thickness) • Cladding, weatherboard, all profiles (fibre cement, 7.5 mm thickness) • Cladding, weatherboard, all profiles (fibre cement, 16 mm thickness) • Cladding, James Hardie EasyLap™ panel (fibre cement, 8.5 mm thickness) • Cladding, all profiles (fibre cement, 9 mm thickness) • Cladding, all profiles (fibre cement, 14 mm thickness) • Flooring, compressed sheet (fibre cement, 18 mm thickness) • Flooring, interior or exterior (fibre cement, 19 mm thickness) • Flooring, underlay (fibre cement, 6 mm thickness) • Interior wall lining (fibre cement, 4.5 mm thickness) • Interior wall lining (fibre cement, 6 mm thickness) • Interior wall lining (fibre cement, 7.5 mm thickness) • Interior wall lining (fibre cement, 9 mm thickness) • Rigid air barrier (fibre cement, 4.5 mm thickness) • Rigid air barrier (fibre cement, 6 mm thickness) • Rigid air barrier (fibre cement, 9 mm thickness) • Soffit / eaves lining (fibre cement, 4.5 mm thickness) • Soffit / eaves lining (fibre cement, 6 mm thickness) • Soffit / eaves lining (fibre cement, 7.5 mm thickness) • Soffit / eaves lining (fibre cement, 9 mm thickness)
Description	A panel, sheet or profile made from a mixture of cellulose fibre from plantation grown radiata pine, Portland cement, sand, water and small quantities of chemical additives.
Platform/source(s) of data	Covers manufacturing at the Rosehill, New South Wales, and Carole Park, Queensland, production sites in Australia (James Hardie, 2017).
Data characteristics	James Hardie, 2017
Age	Manufacturing period 2011–2013.
Technology coverage	James Hardie, 2017
Geographical coverage	Australia
Assumptions	James Hardie, 2017 Declared impacts for Australian-made products used as a proxy for New Zealand-made products. Where available products in New Zealand do not match products in the James Hardie EPD, data in the EPD are pro-rated according to thickness of the product and density.
Completeness/ exclusions	James Hardie, 2017
Plausibility check	No plausibility checks carried out.
Consistency e.g. with EN 15804	The EPD is compliant with EN 15804.

A1.5 Floor linings, excluding timber (interior)

Category	-
Name	Anhydrite, levelling screed
Description	Manufacture of dry mixture of calcium sulphate flowing screed.
Platform/source(s) of data	Bundesverband der Gipsindustrie e.V., 2017
Data characteristics	Bundesverband der Gipsindustrie e.V., 2017
Age	Bundesverband der Gipsindustrie e.V., 2017
Technology coverage	Manufacture of a loose dry mix (Bundesverband der Gipsindustrie e.V., 2017)
Geographical coverage	Manufacture in Germany.
Assumptions	Bundesverband der Gipsindustrie e.V., 2017
Completeness/ exclusions	Bundesverband der Gipsindustrie e.V., 2017
Plausibility check	Greenhouse gas results are 0.11 kg CO_2 eq./kg. This compares to 0.073 kg CO_2 eq./kg, using an EcoInvent 3.3 dataset adjusted to assume manufacture in New Zealand (with New Zealand grid electricity).
Consistency e.g. with EN 15804	EPD is EN 15804 compliant.

Category	-
Name	Carpet - woven broadloom (pile material 500 - 600 g/m^2 polyamide 6.6) Carpet - woven broadloom (pile material 700 - 800 g/m^2 polyamide 6.6) Carpet - tufted wall-to-wall (pile material 1300 - 1400 g/m^2 80% wool and 20% polyamide 6.6, polyester (90% recycled) and textile fabric backing) Carpet - tufted wall-to-wall (pile material 1000 - 1100 g/m^2 80% wool and 20% polyamide 6.6, polyester (90% recycled) and textile fabric backing)
Description	Woven carpet with a pile material consisting of polyamide 6.6 or a blend of 80% sheep wool and 20% polyamide 6.6.
Platform/source(s) of data	EPDs available at https://ibu-epd.com/en/published-epds/ including egetaepper a/s (2016a, 2016b) and Fletco Carpets A/S (2014a, 2014b).
Data characteristics	Data provided on a per m^2 basis.
Age	Reference years for data on which EPDs based not provided. EPDs published in 2014 and 2016.
Technology coverage	Data represent carpets with different pile densities. Carpets have woven textile backing of polypropylene or polyester with a recycled content of 90%, and a textile fabric backing. Woven upper side is continuous died or injection printed.
Geographical coverage	Data represent production in Europe and are therefore not necessarily representative of New Zealand manufactured product.
Assumptions	See EPDs egetaepper a/s (2016a, 2016b) and Fletco Carpets A/S (2014a, 2014b).
Completeness/ exclusions	See EPDs egetaepper a/s (2016a, 2016b) and Fletco Carpets A/S (2014a, 2014b).

Plausibility check	At the time of viewing, 118 EPDs for carpets and carpet tiles were registered on the IBU EPD scheme. For carpets, declared greenhouse gas emissions range from 1.9 kg CO_2 eq./kg (Vebe Floorcoverings B.V. and Mats Inc., 2016) to 8.3 kg CO_2 eq./kg (Vetex Teppichbodenfabrik GmbH & Co. KG., 2014). This compares to 5.1–6.1 kg CO_2 eq./kg for selected carpet EPDs.
Consistency e.g. with EN 15804	EPDs compliant with EN 15804. However, data are not geographically representative of New Zealand production.

Category	-
Name	Linoleum flooring
Description	Heterogeneous or homogeneous composition of vinyl, linoleum, cork or rubber.
Platform/source(s) of data	EPD (European Resilient Flooring Manufacturers Institute, 2013b) available at https://ibu-epd.com/en/epd-programme/.
Data characteristics	Data provided on a per m^2 basis.
Age	Reference year on which EPD is 2011. EPD registered in 2013.
Technology coverage	Calendaring of a homogeneous mixture of linoleum cement, cork flour and/or wood flour, pigments and inorganic fillers onto a fibrous backing. The product then undergoes an oxidative curing process (European Resilient Flooring Manufacturers Institute, 2013b).
Geographical coverage	Represents manufacture by three European companies representing 100% of ERFMI membership.
Assumptions	See European Resilient Flooring Manufacturers Institute (2013b). No reference service life provided.
Completeness/ exclusions	See European Resilient Flooring Manufacturers Institute (2013b).
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	EPD compliant with EN 15804.

Category	-
Name	Vinyl (PVC) floor sheets
Description	Product consists of two polyvinyl chloride backing layers, a photographic layer, an embossed clear polyvinyl chloride wear layer and a protective polyurethane layer
Platform/source(s) of data	EPD (Karndean Design Flooring, 2016) available at www.epd-australasia.com.
Data characteristics	Data provided on a per m^2 basis. The EPD provides results for several vinyl flooring options. Results taken from the "Van Gogh" option which has a stated area density of 5.69 kg/m^2 and is the most sold product in Australia and New Zealand (Karndean Design Flooring, 2016). The product is 3 mm thick.
Age	Reference year on which EPD is based is 2012 for primary data.
Technology coverage	Data represents production at manufacturing sites in South Korea, Taiwan and China. For information about the production process, see Karndean Design Flooring (2016).
Geographical coverage	Manufacture in South Korea, Taiwan and China, for the Australian and New Zealand markets.
Assumptions	Karndean Design Flooring, 2016

Completeness/ exclusions	Karndean Design Flooring, 2016.
Plausibility check	Data specific to New Zealand market. The European Resilient Flooring Manufacturers' Institute (2013a) provides a calculated climate change impact of 2.7 kg CO_2 eq./kg, which is considerably higher than the figure calculated from the Karndean EPD of 1.4 CO_2 eq./kg (Karndean Design Flooring, 2016).
Consistency e.g. with EN 15804	EPD compliant with EN 15804.

A1.6 Glass and materials used in windows

For the following aluminium products, see A1.9 Metals and metal-containing composites:

- Curtain wall extruded frame (aluminium, primary (anodised finish))
- Curtain wall extruded frame (aluminium, primary (powder coated finish))
- Window frame (aluminium, primary (anodised finish), non-thermally broken)
- Window frame (aluminium, primary (powder coated finish), non-thermally broken)
- Window frame (aluminium, primary (anodised finish), thermally broken)
- Window frame (aluminium, primary (powder coated finish), thermally broken)

Category	Argon
Name	Window, IGU, glazing, argon
Description	Production of argon gas for use in IGUs.
Platform/source(s) of data	EcoInvent 3.3.
Data characteristics	Production by catalytic burning of oxygen
Age	See www.ecoinvent.org.
Technology coverage	Density based on standard temperature and pressure. Actual conditions in an IGU likely to vary.
Geographical coverage	Global data in EcoInvent 3.3.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	Large uncertainties reported for process requirements and infrastructure.
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	Glass
Name	Glass, single pane, heat strengthened Glass, single pane, heat strengthened, low emissivity (low-E) finish Glass, single pane, laminated Window, IGU, glazing (float glass) Window, IGU, glazing (float glass, low emissivity (Low-E) finish Window, IGU, glazing (glass, heat strengthened) Window, IGU, glazing (glass, heat strengthened, low emissivity (low-E) finish
Description	Glass is made by combining and heating silica sand, lime and soda before passing over a bed of molten tin followed by controlled cooling. It is normally produced in thicknesses ranging from 2 mm up to 25 mm.

	Float glass may undergo subsequent treatment such as heat strengthening, coating and laminating.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Glass production based on "Flat glass production, uncoated". Heat strengthened glass based on "Flat glass production" and "Tempering, flat glass". Heat strengthened, low E glass based on "Flat glass production, coated" and "Tempering, flat glass". Laminated glass uses an adapted version of "Glazing production, double, U<1.1 W/m^{2}K, laminated safety glass". The original dataset has an input of "Glazing production, double, U <1.1 W/m^{2}K" which includes frame and other elements. These have been removed including aluminium, argon, polybutadiene, polysulphide and zeolite. Statistics NZ data indicate that 68% by value of total imports from 2010 – 2015 of "glass: multiple walled insulating units of glass" came from Singapore followed by USA (14%), China (9%) and Europe (9%). Therefore, electricity required for production is based on the Singapore grid, which is 95.5% supplied by natural gas (Energy Market Authority, 2015).
Age	Various – see www.ecoinvent.org.
Technology coverage	Includes provision of cullet, melting and forming in a float bath, cooling, cutting and storage. Also includes infrastructure. Heat strengthened glass involves a toughening process that may be physical (thermal) or chemical. Data in EcoInvent are based on a thermal tempering process. Low E glass includes cathodic sputtering of a metal coating on the float glass. Laminated glass – includes processes to make a double glazed unit consisting of laminated safety glass with an area of 1.06 m^2.
Geographical coverage	Rest of the World data in EcoInvent 3.1, i.e. outside Europe. Laminated safety glass – electricity use based on the Singapore grid.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	Excludes any packaging used.
Plausibility check	Alcorn (2010) reports an embodied carbon dioxide figure of 2.45 kg CO_2 eq./kg and 27 MJ/kg for the embodied energy of toughened glass. The ICE database (Hammond and Jones, 2011) reports 1.35 kg CO_2 eq./kg and 23.5 MJ/kg for toughened glass, which are closer to the data used here based on EcoInvent 3.1 of 1.22 kg CO_2 eq./kg and 14.6 MJ/kg (for heat strengthened glass). A report for Glass for Europe (PE International, 2011) reports 1.23 kg CO_2 eq./kg of float glass (without heat strengthening). The report also provides a primary energy demand of 15.62 MJ/kg.
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	PVC-U
Name	Window frame (PVC-U)
Description	Manufacture of an extruded PVC frame profile needed to produce a window frame with a 1 m^2 visible area.
Platform/source(s) of data	EcoInvent 3.1

Data characteristics	Based on "window frame production, poly vinyl chloride, U=1.6 W/m^{2}K" in EcoInvent. Dataset adapted to assume manufacture in New Zealand using electricity supplied from the grid (Sacayon Madrigal, 2015).
Age	See www.ecoinvent.org.
Technology coverage	Includes injection moulding and extrusion of PVC, section bar rolling for steel fittings, section bar extrusion for aluminium parts, road transport for production phases. Process data reflects a highly automated process.
Geographical coverage	Global data in EcoInvent 3, with NZ grid electricity.
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	See www.ecoinvent.org

For the following softwood products, see A1.13 Timber and engineered wood:

- Window frame (soft wood [from sustainable forest management practices]), unpainted (indoor/outdoor)
- Window frame (soft wood [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]), unpainted (indoor/outdoor)

A1.7 Insulation

Category	Specific data
Name	• Insulation (90 mm wall), Pink® Batts® Classic R1.8 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Classic R2.2 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Steel R2.2 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® R2.2 Narrow Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Classic R2.4 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® Steel R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® Steel R2.6 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Wall (glass wool) • Insulation (90 mm wall), Pink® Batts® Ultra® R2.8 Narrow Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.2 140 mm Narrow Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R3.6 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Wall (glass wool) • Insulation (140 mm wall), Pink® Batts® Ultra® R4.0 140 mm Narrow Wall (glass wool) • Insulation (masonry wall), Pink® Batts® Masonry R1.0 (glass wool) • Insulation (masonry wall), Pink® Batts® Masonry R1.2 (glass wool) • Insulation (70 mm wall), Pink® Batts® Classic R2.2 70 mm Wall (glass wool)

- Insulation (roof), Pink® Batts® Classic R1.8 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R2.2 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R2.6 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R3.2 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Skillion Roof R3.2 (glass wool)
- Insulation (roof), Pink® Batts® Classic R3.6 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Skillion Roof R3.6 (glass wool)
- Insulation (roof), Pink® Batts® Classic R4.0 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R5.0 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R6.0 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R6.3 Ceiling (glass wool)
- Insulation (roof), Pink® Batts® Classic R7.0 Ceiling (glass wool)
- Insulation (floor), Pink® Batts® SnugFloor® R1.6 Narrow (glass wool)
- Insulation (floor), Pink® Batts® SnugFloor® R1.6 Wide (glass wool)
- Insulation (floor), Pink® Batts® SnugFloor® R2.6 Narrow (glass wool)
- Insulation (floor), Pink® Batts® SnugFloor® R2.6 Wide (glass wool)
- Insulation (acoustic, wall), Pink® Batts® Silencer® 100 mm (glass wool)
- Insulation (acoustic, wall), Pink® Batts® Silencer® 75 mm (glass wool)
- Insulation (acoustic, floor), Pink® Batts® Silencer® Midfloor (glass wool)
- Insulation (blanket, roof), Pink® Batts® BIB R1.2 Blanket (glass wool)
- Insulation (blanket, roof), Pink® Batts® BIB R1.8 Blanket (glass wool)
- Insulation (blanket, roof), Pink® Batts® BIB R2.2 Blanket (glass wool)
- Insulation (blanket, roof), Pink® Batts® BIB R2.4 Blanket (glass wool)
- Insulation (blanket, roof), Pink® Batts® BIB R2.6 Blanket (glass wool)
- Insulation (blanket, roof), Pink® Batts® BIB R3.2 Blanket (glass wool)
- Insulation (industrial (<350°C), light equipment insulation (LEI)), LEI Boards 50 mm (glass wool)
- Insulation (industrial (<350°C), light equipment insulation (LEI)), LEI Boards 25 mm (glass wool)
- Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 25 mm (glass wool)
- Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 50 mm (glass wool)
- Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 75 mm (glass wool)
- Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Boards 100 mm (glass wool)
- Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Blanket 36 kg/m^3 (glass wool)
- Insulation (industrial (<350°C), flexible equipment insulation (FEI)), FEI Blanket 32 kg/m^3 (glass wool)
- Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 25 mm (glass wool)
- Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 38 mm (glass wool)

	• Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 50 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 75 mm (glass wool) • Insulation (industrial (<450°C), intermediate service board (ISB)), ISB Boards 100 mm (glass wool)
Description	Manufacturing of glass fibre insulation materials from recycled window glass at Tasman's Penrose site.
Platform/source(s) of data	Tasman Insulation New Zealand, 2017
Data characteristics	Product specific data.
Age	Primary data collected for the manufacturing period May 2017 to April 2018.
Technology coverage	Includes glass batch mixing (80% of raw material is crushed window glass), melting, temperature conditioning, fiberizing, forming, curing, trimming and packaging.
Geographical coverage	New Zealand
Assumptions	Tasman Insulation New Zealand, 2017
Completeness/ exclusions	Tasman Insulation New Zealand, 2017
Plausibility check	Product specific data, so not plausibility check carried out.
Consistency e.g. with EN 15804	EPD is compliant with EN 15804.

Category	Generic data
Name	Insulation, glass wool (generic)
Description	Insulation product made primarily from recycled glass which is melted at high temperature and spun into fibres to form a blanket or mat.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Original unit process dataset in EcoInvent 3.1 is "Glass wool mat production". Adapted for recycled content, use of NZ grid electricity (Sacayon Madrigal, 2015) and check to ensure diesel combustion has a sulphur content of 10 ppm.
Age	Various – see www.ecoinvent.org. NZ grid electricity data based on 2013 fuel mix.
Technology coverage	EcoInvent 3.1 data used, adapted for New Zealand. Adaptations as follows: Use of NZ grid electricity, medium voltage. Recycled content input adjusted to 80% by mass.
Geographical coverage	Rest of the World data in EcoInvent 3.1 (outside Europe).
Assumptions	Process represented in EcoInvent 3.1 is similar to NZ manufacture, with adjustments set out in Technology coverage.
Completeness/ exclusions	Transport of recycled glass to the insulation plant is not included. No packaging considered.
Plausibility check	Results are higher than figures reported by Tasman Insulation NZ (Tasman Insulation New Zealand, 2017) and lower than overseas published EPD data (Saint-Gobain Argentina S.A. - Div. ISOVER, 2017a, 2017b, 2017c). This is potentially because of the high proportion of

	renewables supplying NZ grid electricity (electricity makes the largest contribution to greenhouse gas emissions at 26%), the high recycled glass content (the EPDs cover product without apparent recycled glass content) and density differences. Calculated greenhouse gas results are similar to other references e.g. (Nebel et al., 2011) with a 4% difference. The ICE database (Hammond and Jones, 2011) shows good agreement, but only presents results for carbon dioxide emissions. Total primary energy of 30 MJ/kg is similar to the figure of 32 MJ/kg quoted by Alcorn (Alcorn) and within the range provided in the ICE database (Hammond and Jones, 2011).
Consistency e.g. with EN 15804	The end-of-waste state of recycled glass is taken as the point at which recycled glass arrives at the glass wool plant.

Category	Generic data
Name	Insulation, mineral wool
Description	Insulation product primarily made from inorganic rocks which are melted at high temperatures and spun into fibres to form a blanket or mat.
Platform/source(s) of data	Knauf Insulation, d.o.o., Skofja Loka, 2014
Data characteristics	Data from an EPD for a specific European plant.
Age	EPD published in 2014.
Technology coverage	Insulation available as slabs, boards and also rolls. Density range is 25 to 160 kg/m³ (with 50 kg/m³ for results published in the EPD). Product consists of inorganic rocks (typically 98%) of stone wool and thermosetting resin binder. The inorganic part is made of volcanic rocks, typically basalt, and also dolomite, with a small amount of mineral wool waste (internal and external), with cement. The process uses a cupola furnace heated by coke.
Geographical coverage	Manufacture in Slovenia (Knauf Insulation, d.o.o., Skofja Loka, 2014).
Assumptions	Manufacture at the Knauf Slovenia plant is representative of manufacture at plants from which mineral wool is imported to New Zealand.
Completeness/ exclusions	Knauf Insulation, d.o.o., Skofja Loka, 2014
Plausibility check	Greenhouse gas and total primary energy results are higher than quoted in the ICE database. Figures are approximately 10% higher than the EcoInvent dataset results for greenhouse gases. Results in another EPD (Center for Life Cycle Assessment and Sustainable Design, 2014) are the lowest found. Input material for this process is 70% recycled, which is likely to account for the lower presented figure.
Consistency e.g. with EN 15804	Data developed consistent with EN 15804 standard.

Category	Generic data
Name	Insulation, polyester
Description	Insulation material based on petrochemicals which is either heat treated or has binding agents added. Product made in New Zealand contains recycled PET (polyethylene terephthalate) bottles.

Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Original unit process dataset is "Fleece production, polyethylene". In the absence of NZ data, EcoInvent 3.1 data used, adapted for New Zealand as follows: Use of NZ medium voltage grid electricity (Sacayon Madrigal, 2015). Recycled content input adjusted to 45% by mass.
Age	Various for EcoInvent data – see www.ecoinvent.org
Technology coverage	Polyester insulation is manufactured in New Zealand, where polyester fibre is used and may contain a minimum of 45% recycled content (Source: Autex website).
Geographical coverage	Global data in EcoInvent 3.1.
Assumptions	EcoInvent data, adapted as indicated in Data Characteristics, is representative of New Zealand manufacture.
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	Freudenberg (Politex s.a.s. di Freudenberg Politex S.r.l., 2015) provides a greenhouse gas impact of 1.8 kg CO_2 eq./kg for a product with 75% recycled content. This work calculates the same impact for a product with 45% recycled content. Calculated total primary energy is higher at 60 MJ/kg compared to 42 MJ/kg reported in the referenced EPD
Consistency e.g. with EN 15804	Includes transport and processing of collected PET bottles for input to the process, so the end-of-waste state is set prior to this collection.

Category	Generic data
Name	Insulation, polystyrene expanded (EPS)
Description	Expanded polystyrene is a rigid foam material made from petrochemicals. Carbon dioxide or pentane may be used as a blowing agent.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Based on "Polystyrene, expandable" in EcoInvent 3.1
Age	See www.ecoinvent.org
Technology coverage	EPS is manufactured in New Zealand using imported polystyrene beads. A low boiling point hydrocarbon, usually pentane gas, is added to the beads to assist the expansion process.
Geographical coverage	Rest of the World (RoW) data in EcoInvent, i.e. excluding Europe.
Assumptions	See www.ecoinvent.org.
Completeness/ exclusions	See www.ecoinvent.org.
Plausibility check	Reported results in ANIQ (Center for Life Cycle Assessment and Sustainable Design, 2015) show reasonable alignment for environmental indicators. The ICE database (Hammond and Jones, 2011) also shows good agreement for greenhouse gas impacts (within 3%). Alcorn (2010) reports a lower greenhouse gas impact at 2.5 kg CO_2 eq./kg (compared to 3.4 kg CO_2 eq./kg used here).

Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	Generic data
Name	Insulation, polystyrene extruded (XPS)
Description	Extruded polystyrene is a rigid foam material made from petrochemicals.
Platform/source(s) of data	Forman Building Systems / Deutschland GmbH & Co. OHG, 2013
Data characteristics	Data reported in an EPD for plants in two European countries. See *Geographical coverage*.
Age	EPD published in 2013 based on manufacturing data from 2010.
Technology coverage	Manufacture of XPS boards within a density range from 30 to 50 kg/m³, supplied in three different compressive strength levels from 100 to 700 kPa within a thickness range of 20 to 200 mm. Covers manufacture by Dow as a weighted average of boards produced at works in Greece and Germany, being 1 m² of XPS board with a thickness of 100 mm, i.e. 0.1 m³ with a density of 35 kg/m³. Boards may have different surfaces (with extrusion skin, planed, grooved or thermally embossed and supplied with butt edge, shiplap and tongue-and-groove profiles. XENERGY is manufactured in a continuous extrusion process. Polystyrene granules are melted together with additives in the extruder under high pressure. Blowing agents are injected into the melted mass and dissolved in it. The melted mass is extruded through a flat die. The drop in pressure causes the polystyrene to foam and cool down to solidify. An endless board of homogenous closed cell polystyrene foam is produced. This is cooled further and then cut to dimensions, trimmed, the surface modified if necessary and packed. Carbon dioxide in combination with process aids is used as a blowing agent.
Geographical coverage	XPS imported into NZ. Plants covered by Forman Building Systems (Forman Building Systems / Deutschland GmbH & Co. OHG, 2013) are based in Europe (Germany and Greece), therefore assumption is that all, or the majority of, XPS board (imported by Forman in NZ) is derived from these two plants.
Assumptions	See Geographical coverage.
Completeness/ exclusions	No significant exclusions.
Plausibility check	Results are dependent on density of product which can vary from 30-50 kg/m³. Results may be adjusted according to the ratio of the following: [Density of product to be considered/Density of product for stated results (35 kg/m³)] * [Thickness of board to be considered/Thickness of board for stated results (100 mm)]. Results adjusted for density show good alignment with other published EPDs (European Extruded Polystyrene Insulation Board Association, 2014; JACKON Insulation GmbH, 2015). Results lower than provided in EcoInvent 3.1 for "RoW: polystyrene production, extruded, CO_2". Comparison of EcoInvent 3.1 data shows that greenhouse gas results are heavily dependent on the blowing agent used, with significantly higher impacts arising from use of HFC 134a as a blowing agent. Results also marginally higher when HFC 152a used as a blowing agent in comparison with carbon dioxide.

	Alcorn (2010) shows lower results at 2.5 kg CO_2 eq./kg although density unknown.
Consistency e.g. with EN 15804	EPD compliant with EN 15804.

Category	Generic data
Name	Insulation, vacuum insulation panel (VIP)
Description	Porous core board of non-combustible fumed silica, mixed with fibres and opacifier. The rigid core board is evacuated and sealed in a gas- and water- tight envelope.
Platform/source(s) of data	Dow Corning Corporation, 2013
Data characteristics	Data reported in an EPD for a specific plant. See *Geographical coverage*.
Age	EPD published in 2013.
Technology coverage	Manufacture of a VIP with a thickness of 20 cm and an area density of 3.7 kg/m^2.
Geographical coverage	Manufacture in Europe.
Assumptions	Dow Corning Corporation, 2013
Completeness/ exclusions	No significant exclusions.
Plausibility check	Data can be compared with another EPD (Porextherm Dammstoffe GmbH, 2013) on a "per m^2" basis. Reported global warming potential values in this EPD are 48.2, 40.6 and 52.7 kg CO_2 eq./m^2 for Vacupor® NT-B2-S/Vacuspeed® (VIP without lamination), Vacupor® PS-B2-S (VIP with EPS lamination) and Vacupor® RP-B2-S (VIP with rubber lamination) respectively. This compares to a value of 39.9 kg CO_2 eq./m^2 reported in (Dow Corning Corporation, 2013).
Consistency e.g. with EN 15804	EPD compliant with EN 15804.

A1.8 Membrane systems

For "Bitumen-based damp-proof course (DPC)", see "Membrane, bitumen, fibre reinforced".

Category	-
Name	K-Dek with TPO membrane, 100 mm thick, R5.00 K-Dek with PVC membrane, 100 mm thick, R5.00
Description	Roof panel system consisting of galvanised and painted steel sheet coils, PVC or TPO membrane, backing film of HDPE and insulation foam.
Platform/source(s) of data	Kingspan Insulated Panels, 2016
Data characteristics	Manufacturing data based on Kingspan's facility located in New South Wales, Australia.
Age	Data based on 2014 manufacturing year.
Technology coverage	A continuous production line is used which includes roll forming, laminating, profiling, cooling, stacking and packaging.
Geographical coverage	Australia, New Zealand and South East Asia
Assumptions	Kingspan Insulated Panels, 2016

Completeness/ exclusions	Kingspan Insulated Panels, 2016
Plausibility check	Data from product specific EPD, so no plausibility check carried out.
Consistency e.g. with EN 15804	EPD compliant with EN 15804.

Category	-
Name	Membrane, bentonite
Description	Sheet membrane consisting of two geotextile membranes needle punched together, between which is a layer of granular sodium bentonite.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Based on "Global" data in EcoInvent 3.1 – market for bentonite, market for fleece, polyethylene and extrusion production, plastic film. Quantities of bentonite and polyethylene based on manufacturer data.
Age	Various – see www.ecoinvent.org
Technology coverage	No data representing production of the membrane itself.
Geographical coverage	Global data – not NZ specific
Assumptions	Data are an approximation only and likely to under-represent impacts of membrane manufacture.
Completeness/ exclusions	No data for production of the bentonite membrane itself. Only data for production of bentonite and polyethylene included.
Plausibility check	No data
Consistency e.g. with EN 15804	Data gap concerning production of the membrane. Data used for production of components based on EcoInvent data.

Category	-
Name	Membrane, bitumen, fibre reinforced
Description	Waterproof membrane system produced by mixing bitumen and polymers reinforced with polyester or glass mat. The system may be fully torched by heating the bottom of the membrane, mechanically fastened by stainless steel fasteners with torching of the top layer, or ballasted, when the membrane is torched and then covered in ballast.
Platform/source(s) of data	EcoInvent 3.1, Bitumen Waterproofing Association, 2013)
Data characteristics	Composition based on a multi-layer fully torched system, as defined by the Bitumen Waterproofing Association EPD for the European bitumen membrane sector. This is derived from 42 plants across 10 European countries. Product used (System 4 in Bitumen Waterproofing Association (2013)) consists of a 3.8 mm top layer with a mass of 4.8 kg per m^2 and a 3.1 mm bottom layer with a mass of 3.7 kg per m^2. Data used to represent production of materials derived from EcoInvent, including: Bitumen seal Limestone production, crushed, washed Polypropylene production, granulate Fleece production, polyethylene Extrusion production, plastic film

	Gravel and sand quarry operation
Age	Data collected in 2010.
Technology coverage	Most bitumen roofing used in New Zealand is 2 layer torch on. Mechanically fastened and ballasted systems are less common.
Geographical coverage	Composition based on European data. Bitumen membrane systems in New Zealand are imported from Europe.
Assumptions	Data are an approximation only and likely to under-represent impacts of membrane manufacture.
Completeness/ exclusions	Composition data accounts for 92% of inputs. Bitumen Waterproofing Association (2013) shows 8% of materials are "other" which are not modelled. The process for making the membrane is also missing, so impacts likely to be under-reported. No packaging included.
Plausibility check	BTC published an EPD for fibre reinforced bitumen waterproofing manufactured in Spain (Sistema de Fabricacion de Laminas Asfalticas, 2015). This shows a greenhouse gas impact per square metre which calculates to 1 kg CO_2 eq./kg (based on the BTC Politax 40 BASIC product). In comparison, the greenhouse gas impact in this work is 0.81 kg CO_2 eq./kg (19% less).
Consistency e.g. with EN 15804	Data gaps do not appear to be compliant with cut off criteria in EN 15804.

Category	-
Name	Membrane, building wrap, polyethylene (PE) Membrane (DPM), polyethylene, underslab, vapour barrier
Description	Used as a damp proofing under concrete slabs and as a synthetic wall underlay.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Includes "Market for polyethylene, high density, granulate", "Market for extrusion, plastic film" and "Packaging film production"
Age	Various – see www.ecoinvent.org
Technology coverage	Covers production of HDPE granulate and extrusion into a sheet.
Geographical coverage	Global
Assumptions	See www.ecoinvent.org
Completeness/ exclusions	See www.ecoinvent.org. Excludes any packaging used.
Plausibility check	Greenhouse gas impact of 2.57 kg CO_2 eq./kg compares to 2.6 kg CO_2 eq./kg for the Association of Plastic Manufacturers in Europe (APME) (Norris, 1999), 2.6 kg CO_2 eq./kg for LDPE film and 1.93 kg CO_2 eq./kg for HDPE from the ICE database (Hammond and Jones, 2011). Total Primary Energy of 86 MJ/kg compares to 51 MJ/kg cited by Alcorn (2010) for building wrap.
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	-
Name	Membrane, polyvinyl chloride (PVC)
Description	Consists of a single sheet of PVC reinforced with polyester fibre used for waterproofing.

Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Based on Global/Rest of the World data in EcoInvent including "Market for polyvinylchloride, suspension polymerised", "Market for fleece, polyethylene" and "Extrusion production, plastic film".
Age	Various – see www.ecoinvent.org
Technology coverage	Data for manufacture of the membrane are missing.
Geographical coverage	Rest of the World, i.e. outside Europe or Global data in EcoInvent 3.1 used.
Assumptions	PVC made by suspension polymerisation as this is the most common method of manufacture (from www.pvc.org/en/p/the-pvc-production-process-explained). Proportion of PVC to polyethylene is 92% to 8% respectively, by mass. Danosa Espana (2015) states PET fibre content of 5%.
Completeness/ exclusions	See Technology coverage. Only production of constituent materials is represented. Packaging and ancillary materials, e.g. used in fixing, excluded.
Plausibility check	Danosa provides a greenhouse gas impact of 5.64 kg CO_2 eq./m^2 for a product with a mass of 1.94 kg/m^2 (DANOSA ESPANA, 2015), giving an impact per kg of 2.9 kg CO_2 eq. This compares to the figure calculated here of 2.63 kg/m^2, 10% less. The ICE database (Hammond and Jones, 2011) provides a higher figure of 3.19 kg CO_2 eq./kg for calendered sheet PVC.
Consistency e.g. with EN 15804	See www.econinvent.org.

Category	-
Name	Membrane, synthetic rubber (EPDM)
Description	Based on a synthetic rubber of ethylene propylene diene monomer used as a waterproofing membrane.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Based on "Market for synthetic rubber" and "Extrusion production, plastic film".
Age	Various – see www.ecoinvent.org
Technology coverage	Only covers production of synthetic rubber and extrusion (based on data for plastic film production).
Geographical coverage	Global
Assumptions	EPDM rubber systems used in New Zealand are primarily manufactured in the USA. Data not tailored to manufacture in this location.
Completeness/ exclusions	See Technology coverage. Packaging and any ancillary materials not included.
Plausibility check	The ICE database (Hammond and Jones, 2011) provides a greenhouse gas impact for general rubber of 2.85 kg CO_2 eq./kg, acknowledging that data are poor and indications are that synthetic rubber shows higher values. This work calculates a value of 3.6 kg CO_2 eq./kg.
Consistency e.g. with EN 15804	See www.ecoinvent.org

A1.9 Metals and metal-containing composites

Category	Aluminium
Name	• Aluminium, primary (anodised finish, one side 0.02 mm), flat sheet, 0.7 mm BMT • Aluminium, primary (anodised finish, one side 0.02 mm), flat sheet, 0.9 mm BMT • Aluminium, primary (anodised, one side 0.02 mm), profile sheet metal, generic all profiles, 0.7 mm BMT • Aluminium, primary (anodised, one side 0.02 mm), profile sheet metal, generic all profiles, 0.9 mm BMT • Aluminium, primary (anodised finish, one side 0.02 mm), louvre blades, 2.0 mm BMT • Aluminium, primary (no finish), profile sheet metal, 0.7 mm BMT • Aluminium, primary (powder coated finish, one side 0.08 mm), flat sheet, 0.7 mm BMT • Aluminium, primary (powder coated finish, one side 0.08 mm), flat sheet, 0.9 mm BMT • Aluminium, flashing (primary (powder coated, one side 0.08 mm), flat sheet, 0.9 mm BMT
Description	Aluminium produced in New Zealand from primary resources is based on bauxite mined and refined into alumina in Australia, which is then shipped to Tiwai Point in the South Island. Once cast at Tiwai Point, the ingots are transported for further processing including extruding, cold rolling, anodising and powder coating.
Platform/source(s) of data	EcoInvent 3.1 – adapted to include New Zealand grid electricity. Based on data from World Aluminium (2013).
Data characteristics	The aluminium model includes mining of bauxite and production of alumina in Australia, shipping to New Zealand, electrolysis and alloying (based on 6060 alloy), casting into ingots, transport to processors (taken as a 1000 km truck journey), where the ingot is either extruded or cold rolled and may be anodised or powder coated. The alloying process is based on the following composition (%): Aluminium (98.475). Cast iron (0.2) Chromium (0.05) Copper (0.1) Magnesium (0.475) Manganese (0.1) Silicon (0.45) Zinc (0.15) Anodising based on "Anodising, aluminium sheet" from EcoInvent 3.1, updated to reflect use of New Zealand medium voltage grid electricity (Sacayon Madrigal, 2015). Powder coating based on "Powder coating, aluminium sheet" in EcoInvent 3.1, updated for NZ grid electricity (medium voltage).
Age	World Aluminium mass flows are based on 2010 data. For age of EcoInvent data – see www.ecoinvent.org
Technology coverage	Aluminium electrolysis based on the prebake process and includes production of wrought aluminium which is cast into ingots, based on the alloy composition in "Data characteristics". Electricity for the aluminium electrolysis process is derived from the Manapouri hydro dam under a contract with Meridian Energy. However, since the electricity is delivered via the grid, there is no current

	mechanism in New Zealand for exclusively purchasing renewable-derived electricity from the grid and since electricity generation at the Manapouri hydro dam contributes towards national grid average emission factors, electricity demand at Tiwai Point was modelled as being supplied by grid average electricity. In 2014, renewables made up 80% of New Zealand grid electricity (MBIE, 2015). Data provided with a range of BMTs. Aluminium results may be generated with no finish, anodised or powder coated. Anodising coating thickness is 20 um. Includes mechanical surface treatment (50% of workpieces), degreasing, pickling, anodising and sealing. Also includes waste water treatment. Powder coating based on a coating thickness of 80 um. The heat consumption is calculated based on a sheet of 2 mm thickness, but is applied to all thicknesses modelled. Includes chromatising of the aluminium sheet, powder coating, heat curing and treatment of wastewater.
Geographical coverage	Rest of the World data in EcoInvent 3.1 (outside Europe).
Assumptions	Heat consumption for powder coating of 2 mm thick aluminium is assumed to be the same for 0.7 mm and 0.9 mm BMT.
Completeness/ exclusions	See www.ecoinvent.org
Plausibility check	Greenhouse gas impact calculated as 10.5 kg CO_2 eq./kg and total primary energy of 142 MJ for a flat sheet (BMT = 2 mm) with no finish up to 11.1 kg CO_2 eq./kg for an anodised or powder coated flat sheet and a total primary energy of 149 MJ. This compares with 11.1 kg CO_2 eq./kg published in EPDs (Gesamtverband der Aluminiumindustrie e.V. (GDA), 2013b, 2013c) with a power mix for aluminium production that is largely renewables (as is the case in NZ). Total primary energy is higher at 190 MJ for coil-coated aluminium sheet (GDA, 2013b) and 202 MJ for cold formed aluminium sheet (GDA, 2013c). EcoInvent data show a large variation in greenhouse gas impacts associated with aluminium production, due primarily to the underlying source(s) of energy supplying the electricity to the process. Where electricity is primarily coal derived, greenhouse gas impacts of aluminium production can be significantly higher. Alcorn's original work shows results that are higher, from 14.2 kg CO_2 /kg for primary aluminium up to 16.35 kg CO_2 /kg for extruded, anodised aluminium (Alcorn, 2010). The ICE database provides values of 12.5 kg CO_2 eq./kg for extruded aluminium and 12.8 kg CO_2 eq/kg for rolled aluminium, providing similar values and showing little difference between extruded and rolled outputs (Hammond and Jones, 2011).
Consistency e.g. with EN 15804	See www.ecoinvent.org

Category	Aluminium composite
Name	Aluminium composite material (ACM) panel, 4 mm thick
Description	Thin sandwich panel of thermoplastic with aluminium sheet on each face, with a thickness of 4 mm.
Platform/source(s) of data	EPD for aluminium composite panels published by Gesamtverband der Aluminiumindustrie e.V. (GDA) (2013a). The EPD represents five

	products weighted by production volumes of two member companies of the GDA.
Data characteristics	Data reported per m² and converted to "per kg" using a reported kg/m² rate of 7.04.
Age	Data collected in 2011 and 2012.
Technology coverage	Represents European manufacture where production technologies are reported as being comparable. For information about production, see the GDA EPD (2013a).
Geographical coverage	Europe. Composite aluminium panels are largely imported into New Zealand.
Assumptions	Manufacture by reporting GDA members, and resulting impacts, are indicative of aluminium composite panel manufacture in countries importing product to New Zealand.
Completeness/ exclusions	Gesamtverband der Aluminiumindustrie e.V., 2013a
Plausibility check	Comparison with an Alucoil EPD (Alucoil, S.A, 2017) for two aluminium composite panel products shows the following differences (with results in the GDA EPD (2013a) providing the baseline: Greenhouse gas: -4.6 to 45% (likely to be heavily influenced by the source of aluminium). Air acidification: within range (0.02 – 0.03 kg SO_2 eq./kg). Resource depletion (fossil fuels): within range (58 – 93 MJ/kg).
Consistency e.g. with EN 15804	EPD is compliant with EN 15804 and has been independently verified.

Category	Steel (structural)
Name	• Steel (primary), structural, columns and beams • Steel (primary), circular hollow section (different sizes), factory painted • Steel (primary), equal angle (different sizes), factory painted • Steel (primary), parallel flange channel (different sizes), factory painted • Steel (primary), rectangular hollow section (different sizes), factory painted • Steel (primary), square hollow section (different sizes), factory painted • Steel (primary), taper flange beam (different sizes), factory painted • Steel (primary), unequal angle (different sizes), factory painted • Steel (primary), universal beams (different sizes), factory painted • Steel (primary), universal columns (different sizes), factory painted • Steel (primary), circular hollow section (different sizes), unpainted at factory • Steel (primary), equal angle (different sizes), unpainted at factory • Steel (primary), parallel flange channel (different sizes), unpainted at factory • Steel (primary), rectangular hollow section (different sizes), unpainted at factory • Steel (primary), square hollow section (different sizes), unpainted at factory • Steel (primary), taper flange beam (different sizes), unpainted at factory • Steel (primary), unequal angle (different sizes), unpainted at factory

	• Steel (primary), universal beams (different sizes), unpainted at factory • Steel (primary), universal columns (different sizes), unpainted at factory
Description	Manufacture of welded beams and columns at the BlueScope Welded Products Plant at Unanderra, New South Wales, Australia from steel made at Port Kembla, Australia. Covers product in the range 350 WC to 1200 WB comprising standard steel grades G300 and G400 with L15 variants. Plate thickness is 10–40 mm. Does not cover specialised highly alloyed grades (from BlueScope Steel Limited, 2015). Other steel structures based on the same data. Where steel structures have factory applied paint, this is based on paint plant data in EcoInvent 3.3.
Platform/source(s) of data	BlueScope Steel Limited, 2015) + EcoInvent for factory painted product.
Data characteristics	Specific EPD for welded beams and columns. Generic data for all other steel structures and factory painting process.
Age	EPD published in 2015 based on data collected 2012–2014.
Technology coverage	Production of steel is by an integrated blast furnace/basic oxygen steelmaking and continuous slab casting, then hot rolling into steel plate. The plate is transported to the Welded Products Plant where it is cut and welded into beams and columns. Product contains 8.5% post-consumer recycled content, and 6.5% pre-consumer recycled content. Variation in declared indicators between standard steel grades is insignificant. For typical composition, see the BlueScope EPD (BlueScope Steel Limited, 2015). Paint plant data covers phosphating of steel, powder coating and heat curing.
Geographical coverage	Australia. Welded beams are also produced in New Zealand from steel plate derived from a unique process that uses iron-rich sands (titanomagnetite) rather than iron ore as a raw material input (Jaques, 2002). No recent data are available for product derived from this process. Paint data are global in EcoInvent.
Assumptions	BlueScope Steel Limited, 2015
Completeness/ exclusions	BlueScope Steel Limited, 2015
Plausibility check	The value of indicators is significantly influenced by the underlying process for manufacturing the steel and the amount of recycled content in the steel product. The ICE database (Hammond and Jones, 2011) reports 2.31 kg CO_2 eq./kg for steel plate with a 35.5% recycled content for the "Rest of the World" (outside Europe), compared to 2.85 kg CO_2 eq./kg from the BlueScope Steel EPD (with a recycled content of 15%). The theoretical greenhouse gas impact for steel plate with no recycled content is 3.27 kg CO_2 eq./kg, excluding cutting of the steel plate. The embodied energy range is 33 MJ/kg (35.5% recycled content) to 45 MJ/kg (hypothetical virgin product) compared to 31.9 MJ/kg from BlueScope Steel.

	Data produced from Nebel, Alcorn and Wittstock provides a carbon dioxide emission of 2.1 kg/kg steel (Nebel et al., 2011). No information provided on source of data, recycled content etc. Data reported as from 2006. worldsteel data for steel plate (blast furnace route) collected using Worldsteel methodology in 2007 shows values that are lower, e.g. global warming impact of 2.35 kg CO_2 eq./kg. Jaques shows 1998 carbon dioxide emissions (only) of 2.45 kg/kg finished plate for production at the NZ plant (Jaques, 2002) excluding production of finished beam from the plate. With expected gains in efficiency since 1998, the figures used here may be conservative for NZ made product. Lack of available data does not allow this to be substantiated.
Consistency e.g. with EN 15804	The EPD was developed in compliance with EN 15804.

Category	Steel (galvanised) – profiles Steel (galvanised) – purlins Steel (galvanised) – stud walls
Name	• Steel, primary (galvanised finish, both sides, 0.02 mm each, coating class Z275), profile metal sheet, generic all profiles, 0.4mm BMT, exposure zone B • Steel, primary (galvanised finish, both sides, 0.02 mm each, coating class Z275), profile metal sheet, generic all profiles, 0.4mm BMT, exposure zone C • Steel, primary (galvanised finish, coating class Z275), cold rolled profile metal sheet, trough section 56mm deep at 305mm ctrs, 0.75 BMT • Steel, primary (galvanised finish, coating class Z275), cold rolled profile metal sheet, trough section 56mm deep at 305mm ctrs, 0.95 BMT • Purlins, DHS (all profiles), steel, primary (galvanised finish, coating class Z275), generic all profiles, exposure zone B • Purlins, DHS (all profiles), steel, primary (galvanised finish, coating class Z275), generic all profiles, exposure zone C • Stud wall system, steel, primary (galvanised finish, 2 sides, 0.02 mm each, coating class Z275), 92.1x33.1 0.55 BMT @ 300ctrs, wall height 4.4-8.8m, 1 nogging row • Stud wall system, steel, primary (galvanised finish, 2 sides, 0.02 mm each, coating class Z275), 92.1x33.1 0.55 BMT @ 450ctrs, wall height 4.4-8.8m, 1 nogging row • Stud wall system, steel, primary (galvanised finish, 2 sides, 0.02 mm each, coating class Z275), 150x33.1 0.75 BMT @ 800ctrs, wall height 4.4-8.8m, 1 nogging row
Description	The zinc coating on galvanised steel provides a cathodic protection. Used as wall and roof framing and as a supporting deck for upper floor structures. Relevant to profiles manufactured from cold-formed galvanized steel sheets between 0.6 – 3.0 mm BMT. Galvanised layer equates to 275 g/m^2 as a cumulative total across both sides of metal. Coating classes per AS 1397-2011 *Continuous hot-dip metallic coated steel sheet and strip – Coatings of zinc and zinc alloyed with aluminium and magnesium*. Coating masses per Table 3.1 of the standard.

Platform/source(s) of data	EcoInvent 3.1 – adapted to include New Zealand grid electricity.
Data characteristics	Includes production of steel, hot and cold rolling, metal coating, onward transport to steel fabricators, and bending/stamping into final product.
Age	Various – see www.ecoinvent.org.
Technology coverage	Based on primary steel production to produce a hot dipped zinc coated steel.
Geographical coverage	Based on Global/Rest of the World (RoW) datasets in EcoInvent 3.1. Medium voltage grid electricity data are for New Zealand (Sacayon Madrigal, 20152015).
Assumptions	See www.ecoinvent.org. No zinc loss in galvanising process. Distance to steel fabricators is 100 km.
Completeness/ exclusions	See www.ecoinvent.org.
Plausibility check	Several EPDs have been published for galvanised steel profiles including: • IFBS (2013) for thin walled profiled sheets used as a wall and roof covering and as a tray in single or double layer roof, wall and ceiling structures. This represents results of 12 member companies producing profiles of 0.75 mm thickness, which additionally includes an organic coating. • European Association for Panels and Profiles (2013) for thin walled profiled sheets used as a wall and roof covering and as a tray in single or double layer roof, wall and ceiling structures. This represents results of 11 member companies producing profiles of 0.75 mm thickness, which additionally includes an organic coating. • Europrofil AB (2015) for light gauge steel profiles produced in Scandinavia. • ArcelorMittal (2019). Greenhouse gas impact of 3–3.74 kg CO_2 eq./kg (depending on BMT) in this work compares to these as follows: 2.4 kg CO_2 eq./kg. 2.4 kg CO_2 eq./kg. 2.54 kg CO_2 eq./kg (for steel 2c in the EPD). 2.54 kg CO_2 eq./kg Use of EcoInvent data results in higher impact than reported in other sources. The iron sand process used in New Zealand for producing steel is unique and therefore comparison with data based on production of steel from iron ore is less meaningful.
Consistency e.g. with EN 15804	Based on EcoInvent.

Category	Steel - reinforcement
Name	Steel, reinforcement, primary, bar
Description	Manufacture of SEISMIC® reinforcing bar at Pacific Steel's facility in Otahuhu, Auckland.
Platform/source(s) of data	Pacific Steel, 2018

Data characteristics	Includes mining of raw materials such as ironsand and coal, transport to and within the manufacturing site, iron and steel manufacture, ancillary service operations, rolling of steel billet to produce bar, and packaging for dispatch to customers.
Age	Data for primary iron and steel making from New Zealand steel updated to reflect manufacturing up to 31 October 2016.
Technology coverage	Pacific Steel manufactures its products using steel billets supplied by New Zealand Steel. These billets are reheated in a furnace at Pacific Steel before being compressed and elongated through rolls. Bar markings and diameters are pressed into the bars. The end product is then cooled.
Geographical coverage	New Zealand.
Assumptions	Pacific Steel, 2018
Completeness/ exclusions	Pacific Steel, 2018
Plausibility check	Product specific data, so no plausibility check carried out.
Consistency e.g. with EN 15804	Data are compliant with EN 15804.

Category	Steel (zinc/aluminium alloy)
Name	• Colorsteel® Endura® 0.4 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B • Colorsteel® Endura® 0.55 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B • Colorsteel® Endura® 0.4 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C • Colorsteel® Endura® 0.55 mm BMT (primary), AZ150 (150 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C • Colorsteel® Maxx® 0.4 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B • Colorsteel® Maxx® 0.55 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone B • Colorsteel® Maxx® 0.4 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C • Colorsteel® Maxx® 0.55 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone C • Colorsteel® Maxx® 0.4 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zones D/E • Colorsteel® Maxx® 0.55 mm BMT (primary), AZ200 (200 g/m^2 ZnAl alloy coating weight (total for both sides) + organic coating, all profiles, exposure zone D/E
Description	Manufacture of Colorsteel® Endura® and Maxx® in BMTs of 0.40 mm and 0.55 mm, at New Zealand Steel's Glenbrook facility in Auckland.
Platform/source(s) of data	New Zealand Steel Limited, 2018

Data characteristics	Raw materials provision e.g. ironsand, coal, limestone, followed by transport to the Glenbrook site, manufacturing from raw material followed by cold reduction (pickling the coil and cold rolling), then coating using New Zealand Steel's aluminium/zinc alloy. This is followed by the paint line, involving pre-treatment, priming, topcoat and backing coat, then packaging for shipment.
Age	Original data from July 2011 to June 2012 updated to reflect manufacturing changes using 2016 data.
Technology coverage	See New Zealand Steel EPD (2018). Update includes new data for oxygen steelmaking furnace, ladle treatment station, slab caster and the reheat furnace of the hot strip mill.
Geographical coverage	New Zealand.
Assumptions	New Zealand Steel Limited, 2018
Completeness/ exclusions	New Zealand Steel Limited, 2018
Plausibility check	Product specific EPD, therefore no plausibility check carried out.
Consistency e.g. with EN 15804	EPD is compliant with EN 15804.

A1.10 Paint

Category	Exterior
Name	• Paint (exterior) water-borne, applied to aluminium (2 coats / m^2) • Paint (exterior) water-borne, applied to steel (2 coats / m^2) • Paint (exterior), water-borne, for masonry (2 coats / m^2) • Paint (exterior), water-borne, for timber (2 coats / m^2) • Paint (exterior), water-borne, primer/sealer (1 coat / m^2)
Description	Paints have traditionally been solvent-based but water-based formulations are more common to reduce emission of volatile organic compounds (VOCs). Waterborne paints include acrylics and co-polymers.
Platform/source(s) of data	AkzoNobel, 2014; Nebel et al., 2011
Data characteristics	Indicators are provided per m^2. Most environmental indicators taken from (AkzoNobel, 2014). This represents two layers except data for primer/sealer which is for one layer. Resource depletion and total primary energy calculated based on reporting of "Paint - resources" in the EPD. Stratospheric ozone depletion indicator taken from Nebel et al. (2011), adjusted for mass per m^2, as this is not reported in the EPD. The following paints were selected from the AkzoNobel EPD: Undercoat – quick dry exterior undercoat pure brilliant white. Weight per layer = 0.083 kg/m^2. Water-based formulation. Exterior Satin – quick dry exterior satin pure brilliant white. Weight per layer = 0.064 kg/m^2. Water-based formulation and contains a fungicide to inhibit mould growth. Masonry – smooth masonry paint pure brilliant white. Weight per layer = 0.136 kg/m^2. Based on an acrylic resin and contains a fungicide for inhibit mould growth.
Age	AkzoNobel EPD published in 2014. Nebel et al. (2011) based on work by Alcorn (2010).

Technology coverage	Pigment is dispersed in a binder and solvent. Tinter added to correct colour and the paint is thinned to the required viscosity, filtered and filled into a packaging container.
Geographical coverage	Production at three sites in the UK. These data are used in the absence of New Zealand specific data.
Assumptions	Production in the UK, and the impacts associated with this, are similar in New Zealand.
Completeness/ exclusions	Stratospheric ozone depletion impacts are not reported in (AkzoNobel, 2014), so figures for this indicator are based on Nebel et al. (2011). There is likely to be differences in the underlying basis of both studies.
Plausibility check	The ICE database (Hammond and Jones, 2011) reports a greenhouse gas emission for waterborne paint of 0.44 kg CO_2 eq./m^2 and notes that embodied carbon figures for paint show a particularly high range in the literature. Figures used in this work for waterborne paints are 0.427 kg CO_2 eq./m^2 for 2 coats of exterior satin paint. Alcorn (2010) reports 1.64 kg CO_2 eq./kg for water based paint. This compares to 2.8 kg CO_2 eq./kg from data produced by Nebel et al. (2011) for water-based paint. Applying the coverage rate of 0.064 kg/m^2 used for this work, the Nebel et al. (2011) greenhouse gas impact equates to 0.36 kg CO_2 eq./m^2 for 2 coats.
Consistency e.g. with EN 15804	EPD produced in accordance with ISO 14025

Category	Interior
Name	• Paint, water-borne, walls (Dulux Wash&Wear® low sheen - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Dulux Wash&Wear® matt - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Dulux Wash&Wear® semi-gloss - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Dulux Wash&Wear® gloss - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Dulux Wash&Wear®+Plus anti bac low sheen - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Dulux Wash&Wear®+Plus kitchen and bathroom semi-gloss - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Dulux Wash&Wear®+Plus kitchen and bathroom low sheen - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Wash&Wear®+plus super hide low sheen - vivid white) (2 coats/m^2) • Paint, water-borne, walls (Wash&Wear®+plus super tough low sheen (parts A&B) - vivid white) (2 coats/m^2) • Paint, water-borne, ceilings (Wash&Wear® kitchen & bathroom ceiling flat) (2 coats/m^2) • Paint, water-based acrylic primer/undercoat (Dulux acrylic sealer undercoat) (1 coat/m^2) • Paint, water-based acrylic primer/undercoat (Dulux professional® total prep) (1 coat/m^2)
Description	Dulux Wash&Wear® paints are for use on interior walls.
Platform/source(s) of data	EPDs (Dulux, 2017c) available at www.epd-australasia.com
Data characteristics	Aggregated datasets.

	Data for Wash&Wear® wall and ceiling paints provided based on 2 coats covering 1 m^2 of wall. Spread rate is 16 m^2/L, representing 0.000125 m^3 paint / m^2 wall. Only data for vivid white paints are provided. VOCs vary by paint from 1 g/L to 55 g/L. Data for preparation paints based on 1 coat covering 1 m^2 of wall. Spread rates are 16 m^2/L for undercoat and 14 m^2/L for total prep, representing 0.000063 and 0.000072 m^3 paint /m^2 wall respectively. VOCs are 2 g/L and 37 g/L respectively. Wall paint results are for 15L tinplate packaging. Modules A1–A3 data apply to 1L, 2L, 4L, 10L and 15L tinplate packaging (reported indicators are within 10%). For further information, refer to the original EPDs
Age	Primary data collected from October 2014 to September 2015.
Technology coverage	Represents Dulux's Rocklea plant.
Geographical coverage	Australia (used as a proxy in the absence of New Zealand specific data).
Assumptions	Dulux, 2017c
Completeness/ exclusions	Dulux, 2017c
Plausibility check	See Paint, water-borne, exterior (generic)
Consistency e.g. with EN 15804	EPD complies with EN 15804.

A1.11 Plasterboard

Category	Specific data
Name	• Plasterboard (GIB® standard 10 mm) • Plasterboard (GIB® standard 13 mm) • Plasterboard (GIB wideline® 10 mm) • Plasterboard (GIB wideline® 13 mm) • Plasterboard (GIB aqualine® 10 mm) • Plasterboard (GIB aqualine® 13 mm) • Plasterboard (GIB braceline® GIB noiseline® 10 mm) • Plasterboard (GIB braceline® GIB noiseline® 13 mm) • Plasterboard (GIB ultraline® 10 mm) • Plasterboard (GIB ultraline® 13 mm) • Plasterboard (GIB fyreline® 10 mm) • Plasterboard (GIB fyreline® 13 mm) • Plasterboard (GIB fyreline® 16 mm) • Plasterboard (GIB fyreline® 19 mm) • Plasterboard (GIB toughline® 13 mm) • Plasterboard (GIB superline® 13 mm)
Description	GIB® Standard plasterboard is an internal lining material available in 10 mm and 13 mm thicknesses. The 10 mm board is suitable for walls, whilst the 13 mm board is recommended for use on ceilings for a better quality finish (Winstone Wallboards, 2017).
Platform/source(s) of data	Winstone Wallboards Limited (2017) available at www.epd-australasia.com
Data characteristics	Aggregated datasets.
Age	Most primary data represent 2015/16 operations.

Technology coverage	Covers all relevant process steps/technologies over the supply chain of the represented cradle to gate inventory with a good overall data quality. The inventory is mainly based on industry data and is completed, where necessary, by secondary data.
Geographical coverage	New Zealand
Assumptions	Winstone Wallboards Limited, 2017
Completeness/ exclusions	Winstone Wallboards Limited, 2017
Plausibility check	No comparisons made as data based on recent, manufacturer specific, New Zealand operations.
Consistency e.g. with EN 15804	EPD complies with EN 15804.

Category	Generic data
Name	Plasterboard (generic)
Description	Gypsum plasterboard comes as sheets consisting of gypsum plaster with fillers and paper linings. They can be produced for specific applications, for example, wet areas.
Platform/source(s) of data	Nebel et al., 2011
Data characteristics	Aggregated dataset.
Age	2005
Technology coverage	Covers all relevant process steps/technologies over the supply chain of the represented cradle to gate inventory with a good overall data quality. The inventory is mainly based on industry data and is completed, where necessary, by secondary data.
Geographical coverage	New Zealand
Assumptions	No information provided.
Completeness/ exclusions	No information provided.
Plausibility check	Results compared to other data sources, specifically: • the ICE database (Hammond and Jones, 2011) • Alcorn, 2010) • the EcoInvent 3.1 database, Good agreement with the ICE database (0.39 kg CO_2 eq./kg compared to 0.32 kg CO_2 eq./kg in this work) and EcoInvent 3.1. Alcorn has a higher figure of 0.47 kg CO_2 eq./kg.
Consistency e.g. with EN 15804	No information provided.

A1.12 Services and infrastructure

Category	Vertical transport
Name	• Elevator (30 floors) - thyssenkrupp momentum - rated load = 1588 kg, speed = 3.56 m/s • Elevator (12 floors) - thyssenkrupp synergy - rated load = 1588 kg, speed = 1.78 m/s • Elevator (5 floors) - thyssenkrupp evolution - rated load = 1000 kg, speed = 1.0 m/s

	• Elevator (3 floors) - thyssenkrupp endura machine room-less - rated load = 1134 kg, speed = 0.76 m/s • Elevator (14 floors) - OTIS Gen2 Stream High Rise® - rated load up to 1850 kg, speed up to 2.5 m/s • Elevator (12 floors) - OTIS Gen2 Stream® - rated load up to 2500 kg, speed up to 2.5 m/s • Elevator (5 floors) - OTIS Gen2 Life® - rated load up to 1000 kg, speed up to 1.6 m/s
Description	Manufacture of elevators
Platform/source(s) of data	EPDs (thyssenkrupp Aufzuge GmbH, 2017; thyssenkrupp Elevator Corporation, 2017a; OTIS Elevator Company, 2018a, 2018b, 2018c).
Data characteristics	Indicators reported in EPDs compliant with Environdec PCR for Lifts (Elevators) version 1.0. Values are expressed as absolute values and/or values per t.km travelled (in which case, the tonne.km value is applied to calculate an absolute value).
Age	Various – see EPDs listed above.
Technology coverage	Values reported for specific elevator products that have a stated number of stops, capacity rated load and rated speed.
Geographical coverage	Europe or North America (depending on the specific EPD).
Assumptions	See EPDs listed above.
Completeness/ exclusions	See EPDs listed above. Some EPDs do not report stratospheric ozone depletion indicators. Where this is the case, a stratospheric ozone depletion impact is estimated based on the stratospheric ozone depletion impact of another elevator (of the same company, for which stratospheric ozone depletion is provided) multiplied by the ratio of greenhouse gas emissions of each of the elevators.
Plausibility check	Reported values in EPDs range from 6,413 kg CO_2 eq./unit to 51,450 kg CO_2 eq./unit.
Consistency e.g. with EN 15804	All EPDs are compliant with ISO 14025.

Category	Energy generation
Name	Energy generation, photovoltaic (PV) system (incl. roof mounts), 3kW
Description	Photovoltaic panels convert solar energy into DC electricity, which is converted to AC electricity by an inverter.
Platform/source(s) of data	EcoInvent 3.1
Data characteristics	Indicators are provided for a complete 3 kW photovoltaic system. Global data including market for photovoltaic mounting system, for flat roof installation, market for photovoltaics, electric installation for 3 kWp module, at building, market for photovoltaic flat roof installation, 3 kWp, single-Si, on roof and market for photovoltaic flat roof installation, 3 kWp, multi-Si, on roof.
Age	See www.ecoinvent.org
Technology coverage	Production of mono-crystalline and poly-crystalline photovoltaic panels.
Geographical coverage	Global data since panels are imported to New Zealand.
Assumptions	New Zealand market is assumed to consist of 50% polycrystalline PV and 50% monocrystalline PV.

	Based on a 250 W panel area occupying an area of 1.58 m^2 (i.e. 0.99 m x 1.6 m), 12 panels needed for a 3 kWp system, which equates to 19 m^2 with a mass of 228 kg (panels only).
Completeness/ exclusions	Packaging and fixing materials excluded.
Plausibility check	Alcorn (2010) provides an embodied carbon figure of 235 kg/m^2. In this work, a 3 kWp system has a greenhouse gas impact of 8250 kg CO_2 eq, which equates to 434 kg CO_2 eq./m^2. Considering only the panels, this reduces to 379 kg CO_2 eq./m^2, still significantly higher than the figure calculated by Alcorn.
Consistency e.g. with EN 15804	See www.econinvent.org

Category	Water and drainage
Name	PVC-U (unplasticised polyvinylchloride), non-pressure pipes, exterior use PVC-U (unplasticised polyvinylchloride), non-pressure pipes, interior use
Description	Manufacture of non-pressure PVC pipes manufactured in Australia from PVC resin and additives, including calcium carbonate, titanium dioxide, organic stabiliser, lubricants and pigments.
Platform/source(s) of data	Iplex Pipelines Australia Pty Ltd, 2017
Data characteristics	Includes production and supply of input materials, transport to manufacturing sites, mixing, extrusion and packaging.
Age	Manufacturing data for 2014.
Technology coverage	Iplex Pipelines Australia Pty Ltd, 2017
Geographical coverage	Australia
Assumptions	Iplex Pipelines Australia Pty Ltd, 2017. Data for exterior applications applied to interior applications also.
Completeness/ exclusions	Iplex Pipelines Australia Pty Ltd, 2017
Plausibility check	No plausibility checks carried out.
Consistency e.g. with EN 15804	EPDs compliant with EN 15804.

A1.13 Timber and engineered wood

Timber and engineered wood data have the suffix "[from sustainable forest management practices]" or "[from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]".

The environmental impacts are the same for all indicators except for climate change. In this case, those products with the suffix "[from sustainable forest management practices]" include the benefit of uptake of carbon dioxide by the growing tree prior to harvesting to process into timber and engineered wood products for use in construction.

Where the suffix "[from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]" is used, the benefit of carbon dioxide by the growing tree is not included.

Further information, and a carbon balance for timber and engineered wood products, is provided in Appendix C.

Category	Engineered wood, cross laminated timber (CLT)
Name	Engineered wood, cross laminated timber (CLT) [from sustainable forest management practices] Engineered wood, cross laminated timber (CLT) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Description	An engineered wood product consisting of layers of softwood laminates glued perpendicular to each other to form a structural product.
Platform/source(s) of data	Wood for Good (www.woodforgood.com)
Data characteristics	Data provided on a per cubic metre basis and converted to a per kg basis using a product density of 488 kg/m^3. 12% moisture content.
Age	Reference year is 2013.
Technology coverage	Manufacture involves logging, sawing and kiln drying, followed by finger jointing of softwood timber pieces to form long laminates which are glued together perpendicular to neighbouring layers and pressed. The grain of each laminate is oriented at right angles to the neighbouring laminate. The grain of outer layers is oriented along the length.
Geographical coverage	Data represent production for the UK market, primarily coming from Europe – 74% of imports are from countries with low carbon (renewables, nuclear) supplying grid electricity.
Assumptions	Production of CLT in Europe, and the impacts associated with it, are similar to New Zealand production. The Wood for Good data are based on a five layer product made from kiln dried softwood. Actual product may be 3, 5 or 7 layers.
Completeness/ exclusions	Timber treatment (if needed). Data are provided as a guide in the absence of locally representative data.
Plausibility check	Results presented in BS Holz (Studiengemeinschaft Holzleimbau e.V., 2015) show a 21% higher greenhouse gas saving and slightly lower total primary energy (5%) (Forest and Wood Products Australia Limited, 2017a) The Wood for Good figures may therefore be considered as conservative.
Consistency e.g. with EN 15804	Underlying data are consistent with EN 15804. However, data are not geographically representative.

Category	Engineered wood, glued laminated timber (glulam, softwood)
Name	Engineered wood, glued laminated timber (glulam, softwood) [from sustainable forest management practices] Engineered wood, glued laminated timber (glulam, softwood) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Description	An engineered wood product consisting of laminations (planks) glued together in parallel to form a higher load bearing structure.
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2017a

Data characteristics	Data provided on a per cubic metre basis and converted to a per kg basis using a product density of 621 kg/m^3. 12% moisture content.
Age	Reference year is 1 July 2015 to 30 June 2016.
Technology coverage	Manufacture involves logging and kiln drying, often rough sawn. The timber is accurately dressed, then typically finger-jointed with adhesive into continuous lengths. The sides of the dressed timber that will be in contact with each other are spread with adhesive and clamped under pressure until the glue has cured.
Geographical coverage	Australia
Assumptions	Forest and Wood Products Australia Limited, 2017a
Completeness/ exclusions	Forest and Wood Products Australia Limited, 2017a
Plausibility check	Figures found vary considerably for greenhouse gas impacts associated with glulam manufacture. The figure of -1 kg CO_2 eq./kg for glulam made from softwood in the FWPA EPD contrasts with: • -1.36 kg CO_2 eq./kg (Alcorn, 2010) • -1.27 kg CO_2 eq./kg (Studiengemeinschaft Holzleimbau e.V., 2018) • -1 kg CO_2 eq./kg (Wood for Good, UK). The American Wood Council and Canadian Wood Council published an EPD for glulam in 2013, based on ISO 21930 (**Error! Reference ource not found.**). This reports greenhouse gas emissions in production, without inclusion of carbon dioxide taken up by the growing tree. A cubic metre has a stated oven dry mass of 533.97 kg. At 50% carbon content, this equates to 533.97 * 50% * (44/12) = 978.9 kg CO_2/m^3 LVL. 197.97 (greenhouse gas impact in EPD) – 978.9 = - 780.93 kg CO_2/m^3. Dividing by the dry mass/m^3 = -780.93/533.97 = -1.46 kg CO_2 eq./kg Therefore, the figure used is conservative compared to other cited figures.
Consistency e.g. with EN 15804	EPD is compliant with EN 15804. However, data are not geographically representative.

Category	Engineered wood, I-joist profile
Name	• Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices] • Engineered wood, I-joist profile, 300x63 [from sustainable forest management practices] • Engineered wood, I-joist profile, 300x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 360x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices] • Engineered wood, I-joist profile, 240x46 [from sustainable forest management practices] • Engineered wood, I-joist profile, 240x90 [from sustainable forest management practices] • Engineered wood, I-joist profile, 360x63 [from sustainable forest management practices] • Engineered wood, I-joist profile, 400x90 [from sustainable forest management practices]

	• Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 300x63 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 300x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 360x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 240x46 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 240x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 360x63 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, I-joist profile, 400x90 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Description	These engineered wood I joists consist of structural laminated veneer lumber (LVL) flanges with a structural plywood web. They may be treated or untreated.
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2017c) for plywood and Wood for Good (www.woodforgood.com) for LVL.
Data characteristics	See *Engineered wood, laminated veneer lumber (LVL)* and *Plywood*
Age	See *Engineered wood, laminated veneer lumber (LVL)* and *Plywood*
Technology coverage	See *Engineered wood, laminated veneer lumber (LVL)* and *Plywood*
Geographical coverage	See *Engineered wood, laminated veneer lumber (LVL)* and *Plywood*
Assumptions	The ratio of LVL to plywood varies with the size of the I-joist but is in the range 64 – 69% LVL, with the remainder being plywood.
Completeness/ exclusions	Includes logging, sawing and kiln drying before production of LVL and plywood. A limitation of these data is that they only comprise the production of LVL and plywood separately. Fabrication into the I beam is excluded due to lack of data. Therefore, the data may be considered as under-representing the impacts of manufacture. Timber treatment is also excluded (if needed). Data are provided as a guide but are likely to under-report impacts.
Plausibility check	The American Wood Council and Canadian Wood Council have published an EPD compliant with ISO 21930 for North American production of wood I joists (**Error! Reference source not found.**). The EPD reports a 10 m length I-joist as having a mass of 36.44 kg (oven dry). Assuming 50% is carbon, this equates to carbon dioxide take up of 36.44 * 50% * (44/12) = -66.8 kg

	The stated greenhouse gas emission figure in the EPD is 16.74 kg CO_2 eq., excluding carbon dioxide absorption. 16.74 – 66.8 = -50.06 kg CO_2 eq. net. -50.06/36.44 = -1.37 kg CO_2 eq./kg (taking into account take up of carbon dioxide by the growing trees making up the product). This compares to a calculated figure of -0.92 kg CO_2 eq used here.
Consistency e.g. with EN 15804	Underlying data for LVL and plywood are consistent with EN 15804.

Category	Engineered wood, laminated veneer lumber (LVL)
Name	Engineered wood, laminated veneer lumber (LVL) [from sustainable forest management practices] Engineered wood, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Description	An engineered wood product consisting of veneers pressed together with phenol formaldehyde resin.
Platform/source(s) of data	Wood for Good (www.woodforgood.com)
Data characteristics	Data provided on a per cubic metre basis and converted to a per kg basis using a product density of 488 kg/m^3. 12% moisture content.
Age	Reference year is 2013.
Technology coverage	Manufacture involves logging, sawing, kiln drying, followed by production of veneers from the softwood logs, drying and then pressing together veneers (with the grain oriented along the length) with resin, followed by trimming to required dimensions.
Geographical coverage	Data represent production for the UK market, primarily coming from Europe – 80% of imports are from countries with low carbon (renewables, nuclear) supplying grid electricity.
Assumptions	Production of LVL in Europe, and the impacts associated with it, are similar to New Zealand production.
Completeness/ exclusions	Timber treatment (if needed). Data are provided as a guide in the absence of locally representative data.
Plausibility check	A carbon footprint report prepared by Scion for New Zealand LVL (Love, 2010) provides a carbon footprint for untreated LVL of -720.75 kg CO_2 eq./m^3 LVL and for treated LVL of -611.42 kg CO_2 eq./m^3. The American Wood Council and Canadian Wood Council published an EPD for LVL, based on ISO 21930 (**Error! Reference source not ound.**). This reports greenhouse gas emissions in production, without inclusion of carbon dioxide taken up by the growing tree. A cubic metre has a stated oven dry mass of 545.87 kg. At 50% carbon content, this equates to 545.87 * 50% * (44/12) = 1000.76 kg CO_2/m^3 LVL. 201.8 (greenhouse gas impact in EPD) – 1000.76 = -798.96 kg CO_2/m^3. Dividing by the dry mass/m^3 = -798.96/545.87 = -1.46 kg CO_2 eq./kg The Wood for Good figure of -1.1 kg CO_2 eq./kg is conservative by comparison.
Consistency e.g. with EN 15804	Underlying data are consistent with EN 15804. However, data are not geographically representative.

Category	Engineered wood, MDF (specific data)

Name	MDF, thick, coated (average thickness 18 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) MDF, thick, uncoated (average thickness 20 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management) MDF, thin, uncoated (average thickness 3 mm), Daiken New Zealand Ltd (with wood sourced from sustainable forest management)
Description	An engineered wood product consisting of veneers pressed together with urea – formaldehyde - melamine type resins.
Platform/source(s) of data	Daiken New Zealand Limited & Daiken Southland Limited, 2019
Data characteristics	Data provided per square metre with moisture contents of 6.5–8%.
Age	Data are for the 2017/18 financial year (April–March).
Technology coverage	Includes growth of forest, logging, transport of logs and woodchips to the manufacturing facility, de-barking, chipping, chip/fibre washing, resin application, drying, mat forming, pressing, sanding and cutting and packaging.
Geographical coverage	New Zealand.
Assumptions	Daiken New Zealand Limited & Daiken Southland Limited, 2019
Completeness/ exclusions	Daiken New Zealand Limited & Daiken Southland Limited, 2019
Plausibility check	Product specific EPD. No plausibility check carried out.
Consistency e.g. with EN 15804	EPD is compliant with EN 15804.

Category	Engineered wood, plywood (exterior, A-bond)
Name	• Engineered wood, plywood (exterior, A-bond) [from sustainable forest management practices] • Engineered wood, exterior cladding, plywood (exterior, A-bond) [from sustainable forest management practices] • Engineered wood, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Engineered wood, exterior cladding, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Description	"Plywood is a panel product made of thin veneers of wood peeled from softwood and hardwood logs and bonded by resin. Plywood product are either engineered wood panels (such as structural plywood and formwork plywood) or non-structural panels (such as interior and exterior plywood)" (Forest and Wood Products Australia Limited, 2017c).
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2017c
Data characteristics	EPD – figures used for exterior plywood, A-bond, 9 mm (structural). Sector average data (90% of Australian plywood manufacture).
Age	EPD published in 2015. Wood input data from a CSIRO study undertaken for the FWPA (Forest and Wood Products Australia Limited, 2009).

Technology coverage	The EPD covers six plywood products from which indicators for exterior plywood, A bond, 9 mm (structural) are used. This has a mass per m^2 of 5.42 kg and a density of 602 kg/m^3. Includes an Australian industry average of total preservative use across all plywood product types.
Geographical coverage	Australia. Used in the absence of recent publically available New Zealand data.
Assumptions	Forest and Wood Products Australia Limited, 2017c. In using these data, the assumption is that New Zealand production of plywood would yield similar environmental impacts.
Completeness/ exclusions	Forest and Wood Products Australia Limited, 2017c
Plausibility check	Results compared to other data sources, specifically: • the ICE database (Hammond and Jones, 2011) • Wood for Good Lifecycle database (www.woodforgood.com) where figures "per m^3" have been adjusted on a "per kg" basis, using a stated density of 491 kg/m^3 for plywood. Greenhouse gas results appear to vary across information sources. The ICE database figures show fossil carbon dioxide of 0.45 kg CO_2 eq./kg and biomass carbon dioxide of 0.65 kg CO_2 eq/kg, providing an A1–A3 impact of -0.2 kg CO_2 eq/kg. Wood for Good greenhouse gas figure is -1.39 kg CO_2 eq./kg (5% moisture), for a less dense product (491 kg/m^3 compared to 602 kg/m^3). This compares to -0.54 kg CO_2 eq./kg calculated from the FWPA EPD.
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

Category	Engineered wood, post tensioned timber frame structure
Name	Post tensioned timber frame structure, laminated veneer lumber (LVL) [from sustainable forest management practices], inc. steel reinforcing Post tensioned timber frame structure, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], inc. steel reinforcing
Description	An engineered wood product consisting of veneers pressed together with phenol formaldehyde resin, prestressed with steel rod.
Platform/source(s) of data	Wood for Good (www.woodforgood.com) for LVL, EcoInvent 3.1 for steel.
Data characteristics	Based on drawings for a New Zealand building that uses a hybrid LVL structural system, the proportion of steel by mass is 4.45% with the remainder being LVL. For LVL, see *Engineered Wood, Laminated Veneer Lumber (LVL)* Steel rod data are based on Pacific Steel, 2018).
Age	Reference year is 2013 for LVL data.
Technology coverage	For LVL, see *Engineered Wood, Laminated Veneer Lumber (LVL)* Steel rod data based on Pacific Steel (2018).
Geographical coverage	For LVL, see *Engineered Wood, Laminated Veneer Lumber (LVL)* Steel data based on manufacture in New Zealand (Pacific Steel, 2018).
Assumptions	The hybrid LVL system is prefabricated in Christchurch. This provides the basis for calculating transport distances. It is assumed that the prefabrication process produces 0.5% steel waste and 2.5% LVL waste by mass (these values being half the waste of

	structural steel and LVL at construction sites in the module A5 datasheet). The lower wastage rates are applied assuming that a controlled factory environment provides an easier environment for reducing and managing waste. All waste steel is assumed to be recycled and all waste LVL is assumed to be landfilled. For LVL, see *Engineered Wood, Laminated Veneer Lumber (LVL)*
Completeness/ exclusions	The data include production of LVL and steel rod and their transport to Christchurch, where it is assumed that the hybrid LVL system is prefabricated. Transport distances are based on the module A4 datasheet. No data are available for the manufacture of the hybrid LVL system, including what energy and consumables are required and what wastes are produced. Timber treatment is also excluded (if needed). Data are provided as a guide and are likely to under-report indicators.
Plausibility check	No data have been found for comparison.
Consistency e.g. with EN 15804	Underlying LVL data are consistent with EN 15804 but not geographically representative. Data gaps exist including manufacture of the prefabricated system.

Category	Timber, softwood
Name	• Timber, softwood, dressed kiln-dried sections [from sustainable forest management practices] • Timber, exterior cladding construction, soft wood, dressed kiln-dried sections [from sustainable forest management practices] • Timber wall framing, soft wood, dressed kiln-dried sections [from sustainable forest management practices] • Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from sustainable forest management practices] • Timber, structural framing, soft wood, dressed kiln-dried, interior use [from sustainable forest management practices] • Timber structural framing, soft wood, dressed kiln-dried, exterior use [from sustainable forest management practices] • Timber, softwood, dressed kiln-dried sections [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Timber, exterior cladding construction, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry] • Timber wall framing, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Timber, structural framing, soft wood, dressed kiln-dried, interior use [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry] • Timber structural framing, soft wood, dressed kiln-dried, exterior use [from unsustainable forest management practices, don’t know or won’t ensure from sustainable forestry]
Description	Dressed, kiln dried softwood, with a moisture content of 12% and a density of 550 kg/m^3.
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2015c

Data characteristics	Sector average EPD for Australian production of softwood timber.
Age	EPD published in 2015. Wood input data from a CSIRO study undertaken for Forest and Wood Products Australia (2009).
Technology coverage	Includes forestry operations, sawing and drying of softwood timber.
Geographical coverage	Australia. Used in the absence of recent NZ data.
Assumptions	Dominant softwood species is radiata pine (*Pinus radiata*). Other softwood species used include hoop pine (*Araucaria cunninghami*) and maritime pine (*Pinus pinaster*). For other assumptions, see Forest and Wood Products Australia Limited, 2015c. In using these data, the assumption is that New Zealand production would yield similar environmental impacts.
Completeness/ exclusions	Timber treatment and any packaging used.
Plausibility check	Alcorn (2010) provides a value of -1.32 kg CO_2 eq./kg for kiln dried, dressed and treated timber. Wood for Good (www.woodforgood.com) has a value of -1.41 kg CO_2 eq./kg for kiln dried sawn softwood. The FWPA figure used here is -1.25 kg CO_2 eq./kg (Forest and Wood Products Australia Limited, 2015c), showing reasonable agreement (maximum of 11% difference)
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

Category	Floor (hardwood)
Name	Hardwood (dressed, kiln-dried) floor [from sustainable forest management practices], with galvanised fixings Hardwood (dressed, kiln-dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
Description	Data represent a dressed kiln dried hardwood with a 12% moisture content and a density of 784 kg/m^3. Galvanised fixings included in module A5 (see Appendix A2).
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2015a
Data characteristics	Sector average EPD for Australian production of softwood timber.
Age	EPD published in 2015. Wood input data from a study for the FWPA by CSIRO (Forest and Wood Products Australia Limited, 2009).
Technology coverage	Includes forestry operations, sawing and drying of hardwood timber.
Geographical coverage	Australia.
Assumptions	Forest and Wood Products Australia Limited, 2015a
Completeness/ exclusions	Timber treatment and any packaging used.
Plausibility check	No comparative data found.
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

Category	Floor (MDF)
Name	MDF (floor) [from sustainable forest management practices], with galvanised nails (generic) MDF (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised nails (generic)
Description	Medium density fibreboard made mainly from *Pinus radiata.* Galvanised fixings included in module A5 (see Appendix A2).
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2017b
Data characteristics	Sector average EPD providing data for E1 standard melamine coated and E1 moisture resistant melamine coated variants. Data selected represent an 18 mm standard board.
Age	EPD published in 2015. Wood input data from a study for the FWPA by CSIRO (Forest and Wood Products Australia Limited, 2009).
Technology coverage	Includes forestry operations, production of resin and wax, blending of wood particles with resin and wax, pressing of the mixture to create the MDF substrate, cutting and sanding.
Geographical coverage	Australia.
Assumptions	Forest and Wood Products Australia Limited, 2017b
Completeness/ exclusions	Packaging.
Plausibility check	An EPD published by Unilin shows a value of -1.02 kg CO_2 eq./kg (UNILIN Division Panels, 2015) and another by Fritz Egger shows -0.93 kg CO_2 eq./kg (Fritz EGGER GmbH & Co. OG, 2015), which compare to -0.18 kg CO_2 eq./kg from the FWPA (Forest and Wood Products Australia Limited, 2017b).
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

Category	Floor (particleboard)
Name	Particleboard (floor) [from sustainable forest management practices], with galvanised fixings Particleboard (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
Description	Particleboard made mainly from *Pinus radiata.* Galvanised fixings included in module A5 (see Appendix A2).
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2015b
Data characteristics	Sector average EPD providing data for a range of particleboard products, including E1 standard melamine coated, E1 moisture resistant melamine coated and flooring (tongue & groove). Data selected represent a 19 mm floor.
Age	EPD published in 2015. Wood input data from a study for the FWPA by CSIRO (Forest and Wood Products Australia Limited, 2009).
Technology coverage	Includes forestry operations, production of resin and wax, blending of wood particles with resin and wax, pressing of the mixture to create the particleboard substrate, cutting and sanding.

Geographical coverage	Australia.
Assumptions	Forest and Wood Products Australia Limited, 2015b
Completeness/ exclusions	Packaging.
Plausibility check	An EPD by Sonae Arauco shows a value of -1.15 kg CO_2 eq./kg (Sonae Arauco, S.A., 2016) and another by Financiera Maderera shows -1.06 kg CO_2 eq./kg (FFINANCIERA MADERERA S.A, 2017), which compare to -0.42 kg CO_2 eq./kg from the FWPA EPD (Forest and Wood Products Australia Limited, 2015b).
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

Category	Floor (plywood)
Name	Plywood (A-bond, floor) [from sustainable forest management practices], with galvanised fixings Plywood (A-bond, floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
Description	"Plywood is a panel product made of thin veneers of wood peeled from softwood and hardwood logs and bonded by resin. Plywood product are either engineered wood panels (such as structural plywood and formwork plywood) or non-structural panels (such as interior and exterior plywood)" (Forest and Wood Products Australia Limited, 2017c). Galvanised fixings included in module A5 (see Appendix A2).
Platform/source(s) of data	Forest and Wood Products Australia Limited, 2017c
Data characteristics	EPD – figures used for exterior plywood, A-bond, 15 mm (flooring). Sector average data (90% of Australian plywood manufacture).
Age	EPD published in 2015. Wood input data from a study for the FWPA by CSIRO (Forest and Wood Products Australia Limited, 2009).
Technology coverage	The EPD covers six plywood products from which indicators for exterior plywood, A bond, 9 mm (structural) are used. This has a mass per m^2 of 9.03 kg and a density of 602 kg/m^3. Includes an Australian industry average of total preservative use across all plywood product types.
Geographical coverage	Australia. Used in the absence of recent publically available New Zealand data.
Assumptions	Forest and Wood Products Australia Limited, 2017c. In using these data, the assumption is that New Zealand production of plywood would yield similar environmental impacts.
Completeness/ exclusions	Forest and Wood Products Australia Limited, 2017c
Plausibility check	Results compared to other data sources, specifically: • the ICE database (Hammond and Jones, 2011) • the Wood for Good Lifecycle database (www.woodforgood.com) where figures "per m^3" have been adjusted on a "per kg" basis, using a stated density of 491 kg/m^3 for plywood. Greenhouse gas results appear to vary across information sources. ICE database figures show fossil carbon dioxide of 0.45 kg CO_2 eq./kg and

	biomass carbon dioxide of 0.65 kg CO_2 eq./kg, providing an A1–A3 impact of -0.2 kg CO_2 eq./kg. Wood for Good greenhouse gas figure is -1.39 kg CO_2 eq./kg (5% moisture), for a less dense product (491 kg/m^3 compared to 602 kg/m^3). This compares to -0.54 kg CO_2 eq/kg calculated from the Forest and Wood Products Australia Limited EPD (2017c).
Consistency e.g. with EN 15804	EPD prepared consistent with EN 15804.

Category	Floor (softwood)
Name	Softwood (dressed kiln-dried) floor [from sustainable forest management practices], with galvanised fixings Softwood (dressed kiln-dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
Description	See *Timber, softwood*. Galvanised fixings included in module A5 (see Appendix A2).

A2. Construction process stage (modules A4–A5)

Indicators are calculated per kg, per m^2 or per unit (depending on the material or product) incorporated into the building (which may be obtained from an output from a BIM model or by applying square metre rates).

Generic transport distances from the last manufacturing, fabrication or assembly process (in the product stage) to a construction site in either Auckland, Wellington or Christchurch CBD are provided in the module A4 datasheet.[21] The basis for derivation of these transport distances is provided in Dowdell et al., 2016). All transport is modelled on a tonne.km basis as one-way loaded journeys only. This is primarily due to the lack of parameterisation in available transport data in EcoInvent 3.1 making it difficult to account for empty return journeys.[22] Also, there is a lack of generic utilisation data by product available.

Packaging of construction materials and products, including use of pallets, is not considered. Therefore, manufacture of the packaging[23] and its subsequent end of life are not included. In general, ancillary materials (for example, required for fixing such as nails, screws and bolts and release agents for concrete) are not currently included (except for timber and engineered wood flooring products). Use of power tools is also not included.

Where data include use of diesel on a construction site, the EcoInvent 3.1 data "diesel, burned in building machine" are used, adapted to reflect a 10 ppm sulphur content, i.e. 4 E^{-7} kg sulphur dioxide per MJ, from:

1 MJ diesel = 1/43 kg = 0.023 kg diesel

[21] All datasheets are available at www.branz.co.nz/buildinglca under "Data".
[22] Through communication with The EcoInvent Centre, it is understood that parameterised truck transport data are likely to be developed in the future.
[23] Product manufacturing data derived from EPDs includes packaging, where it is used.

$4\ E^{-7}$ kg SO_2 * (16/32) = $2\ E^{-7}$ kg S

$2\ E^{-7}$ kg S/0.023 kg diesel = <10 ppm S

Where products are lifted (for example, from a delivery truck), an empirical formula is used as a basis for calculating the energy required (Athena Sustainable Materials Institute, 2015). A lift height of 6 m using diesel as a source of fuel, gives an energy figure of 0.151 MJ/kg lifted (6 m). This is applied universally on the basis that energy required for lifting materials is not significant across the building life cycle.

Material and product waste generated at the construction site is based on the module A5 datasheet, which also sets out the fate of any generated waste. For example, for a product for which 5% is waste during construction, modules A4–A5 accounts for transport of 1.05 kg of the product for every 1 kg that is incorporated in the building.

The manufacture of the additional 0.05 kg required that becomes waste (per kg incorporated in the building) is also accounted for in modules A4–A5, based on environmental indicators calculated for modules A1–A3.

For waste transported to landfill or cleanfill, 20 km is assumed. For waste that requires further transport and/or processing before reaching the "end-of-waste state", this is included in modules A4–A5.

Specific information about materials and products, where relevant, is provided below. Where no specific information is provided, the approach set out in this section is applied.

A2.1 Aggregates

Description	Energy required for moving based on 0.4 kg diesel /m^3. Applying a density of 2240 kg/m^3 for sand and a net heat value of 43 MJ/kg (Eng et al., 2008), provides an energy use (MJ) per kg of (0.4 * 43)/2240 = 0.0076 MJ/kg. The same value is applied to gravel and clay.

A2.2 Clay (fired)

Description	Sanitary ware assumed to be imported from Europe. No wastage on construction site. Packaging not included.

A2.3 Concrete

Description	<u>Reinforcement</u> Separate transport of all in-situ concrete and reinforcement (including concrete and reinforcement wasted at the construction site) is accounted in modules A4–A5, as is onward transport and processing of the waste. <u>Formwork and falsework</u> Formwork is a temporary structure, supported by falsework, which provides a mould into which plastic concrete is poured and retained until it has cured sufficiently to support required loads. It also imparts the required surface finish (Cement & Concrete Association of New Zealand, 2010). There are many variables concerning formwork (and falsework), including:

The type of structure being constructed, for example, whether a wall, beam, column or slab.

The amount of bracing required, including choice of spans between studs and centres between walers or bearers.

The type of materials used, for example, plywood, metal or timber. A full list of materials that may be used as formwork is provided (Cement & Concrete Association of New Zealand, 2010).

Whether the formwork is reusable or designed for a once only use. The number of times reusable formwork may be used is dependent, in part, on appropriate storage and maintenance.

Temporary formwork is not currently included. A report which compared structural concrete and steel frames notes "the concrete structural frame has more associated energy use, CO_2, CO, NO_2, particulate matter smaller than 10 micrometres, SO_2 and hydrocarbon emissions due to more temporary materials, particularly formwork, larger transportation impacts due to a larger mass of materials, and longer equipment use due to the longer installation process" (Lemay, 2011). The paper goes on to conclude that when evaluating buildings over a 50 year life, "the differences noted in the construction stage disappear and the use phase dominates".

This conclusion suggests that the exclusion of temporary formwork is not material at the building level and is therefore reasonable to exclude.

Permanent formwork may also be used in construction, for example, in upper floor applications which use precast concrete (e.g. double tees) or galvanised steel profiles, into which ready mixed concrete is poured to provide a floor surface. Permanent formwork is considered.

<u>Placing on site (in situ concrete)</u>

Assumption is that 0.6 L diesel are used per cubic metre pumped, based on anecdotal data provided by Hawkins Construction Limited.

Aggregate is recovered from some wet concrete left over from the construction site. The amount is set out in the module A5 datasheet. Washing of concrete to recover aggregate is additional to modules A1–A3 impacts, as the data do not cover this activity. Water use to recover aggregate is based on CCANZ (Cement & Concrete Association of New Zealand, 2011) assuming a truck makes 4 trips in a day, each carrying 7 m^3 of concrete.

Reinforcement is collected and most transported for recycling which occurs overseas.

<u>Placing on site (plaster and grout)</u>

Assume 1 part water is added to 6 parts dry plaster at the construction site, based on NZS 4251.1:2001 (Appendix C, C2). Transport of plaster to the construction site is therefore based on a mass of 0.86 kg per kg used in the build, multiplied by the waste factor from the module A5 datasheet. Tap water is used, the supply of which is represented by the EcoInvent 3.1 dataset "tap water production, conventional treatment".

Mixing of plaster is based on the EcoInvent 3.1 dataset "plaster mixing" adapted to include NZ grid electricity (Sacayon Madrigal, 2015).

Since data for production of grout is based on in situ concrete data, it is assumed brought to site wet.

<u>Placing on site (mortar)</u>

3 litres of tap water per 20 kg bag of mortar, based on New Zealand product literature. Transport of dry mortar to the construction site is

	therefore 0.87 kg (per kg of wet mortar) plus 5% for wastage (from A5 datasheet). Supply of tap water is represented by the EcoInvent 3.1 dataset "tap water production, conventional treatment". Data does not include mixing of mortar and disposal of mortar packaging. Waste mortar disposed to landfill (from A5 datasheet).

A2.4 Floor linings, excluding timber (interior)

Description	Anhydrite, levelling screed Water and electricity consumption to install screed amounts to 0.0003 m^3 water/kg screed and 4.43 e-5 kWh of electricity (low voltage) (Bundesverband der Gipsindustrie e.V., 2017). Supply of tap water is represented by the EcoInvent 3.1 dataset "tap water production, conventional treatment" and electricity is based on, based on an average of 2015 – 2017 supply in New Zealand (Sacayon Madrigal, 2015). Carpets Transport to construction site is based on *6511 Carpet finish to floors and walls* in module A4 datasheet. No specific construction site waste rate provided for carpet in the module A5 datasheet, except a rate of 10% for miscellaneous materials. Data in EPDs for carpets (egetaepper a/s, 2016a Fletco Carpets A/S, 2014a, 2014b) indicate a wastage rate of 9% which has been adopted. All waste carpet assumed to go to landfill and represented using data for 100% landfilling scenarios in referenced EPDs. Transport to landfill assumes 20 km. Ancillary materials (e.g. adhesive, carpet gripper), polyethylene packaging, separate underlay not included. Vinyl (PVC) floor sheets Values taken from Karndean Design Flooring EPD (2016).

A2.5 Glass and materials used in windows

Description	Module A4 transport may be based on 4211 Proprietary Curtain Walling and 4611 Exterior Glazing, both of which show different transport distances according to the module A4 datasheet. To simplify modelling of reference buildings, all modelling of glass is based on distances provided for 4611 Exterior Glazing, even if used as part of a curtain wall.

A2.6 Insulation

Description	Given the bulky nature of insulation products, calculation of transport impacts on a tonne.km basis may under-represent the impacts arising from transport, which may be volume rather than mass constrained. Vacuum insulation panels Manufactured to specific sizes, therefore no waste assumed at the construction site.

A2.7 Membrane systems

Description	K-Dek

	Values taken from Kingspan Insulated Panels EPD (Kingspan Insulated Panels, 2016). Membrane, bitumen, fibre reinforced Fibre reinforced bitumen membranes are typically torched on. Using figures in a BWA EPD (Bitumen Waterproofing Association, 2013), 0.4 kg of propane is required to torch on 1 m^2 of membrane. With a mass per m^2 of 8.5 kg, this equates to 0.047 kg propane per kg of fibre reinforced bitumen membrane. With a net heat value of 46.3 MJ/kg for propane (Eng et al., 2008), the energy from propane required is 2.18 MJ/kg membrane. Combustion of propane is represented by the EcoInvent 3.1 data "propane, burned in building machine" and production of propane is represented by the data "propane extraction, from liquefied petroleum gas". Both data are Global.

A2.8 Metals and metal-containing composites

Description	Aluminium Module A4 transport distances for aluminium (from the module A4 datasheet) vary depending on application between *3612 Minor structures, 4232 Metal and metal faced sheet cladding, 4241 Metal profile sheet cladding* and *4363 Fully supported flat aluminium sheet roofing* and *4521 Aluminium windows and doors*. For the purposes of simplifying modelling of reference buildings, all transport of aluminium is based on *4521 Aluminium windows and doors* whether used in this or another application (due to the significance of aluminium use as window framing in New Zealand compared to other construction applications). Aluminium composite Transport of aluminium composite panel is based on *4257 Metal clad insulating cladding* in the module A4 datasheet. Steel structural, galvanised (profiles), galvanised (purlins) and galvanised (stud walls) In the module A4 datasheet, transport of structural steels (beams, studs and structural profiles) is based on *3411 Structural steelwork.* Transport of steel profiles or sheets e.g. used as cladding, is based on *4311 Profiled metal sheet roofing.* In the module A5 datasheet, steel I beams, galvanised steel studs and trough profiles are treated as structural steel. Steel profile sheet, used as a cladding, is treated as steel (sheet). End-of-waste state for Metals Aluminium and steel waste generated at the construction site is considered to reach its end-of-waste state on disposal at the construction site, due to its clean nature. No further processing or transport is considered from this point.

A2.9 Paint

Description	<u>Exterior</u> Indicators are taken from AkzoNobel EPD (2014) and includes paint distribution, paint use, transport and paint and packaging end of life. These data have been used to ensure account of any emissions during paint use. However, this means that default transport distances from the module A4 datasheet have not been able to be used. The EPD does not appear to include manufacture of paint that becomes waste in this module. Therefore, this is added in, based on the waste rate in the module A5 datasheet. The AkzoNobel EPD (2014) data include end of life routes for paint and containers (either polypropylene or tin cans). The designation of the waste paint as a hazardous or non-hazardous waste in the EPD is based on the EU Dangerous Preparations Directive (1999/45/EC). Data for painting of metals assumed to be the same as data for painting of timber. <u>Interior</u> Modules A4–A5 data represent those published in EPDs (Dulux, 2017c). Therefore, these represent distribution via hubs and then couriering to customers or collection by customers in store in Australia. Where a paint is tinted before use, the typical volume of tinter is included, as is electricity for mixing the tinter and disposal of tinter packaging. Paint waste rate in module A5 based on a commercial painting scenario (as opposed to DIY) which gave a 1.5% paint waste rate, of which 1% left in pail and assumed to be landfilled and 0.5% left on roller and assumed to go to wastewater treatment following washing. Recycling of paint cans based on an Australian average of 41% (for tinplate). VOC emissions during application and drying of paint are included. Therefore defaults in the module A4 and module A5 datasheets have not been able to be used.

A2.10 Plasterboard

Description	<u>Specific data</u> Values taken from Winstone Wallboards EPD (2017).

A2.11 Services and infrastructure

Description	<u>Vertical transport</u> Elevator data comes from EPDs with a geographical scope in Europe and USA (thyssenkrupp Aufzuge GmbH, 2017; thyssenkrupp Elevator Corporation, 2017a; OTIS Elevator Company, 2018a, 2018b, 2018c). It is assumed that elevators made in these regions are imported to New Zealand, using the Distance Mode Model in the A4 datasheet (plus 100 km for transport by truck in New Zealand). Installation data are taken directly from the EPDs. <u>Water and drainage</u> Based on values in the Iplex EPD (2017).

A2.12 Timber and engineered wood

Description	Module A4 transport is based on the module A4 datasheet, which has different transport distances for timber according to the classifications *3811 Prefabricated Timber Elements, 3812 Timber Platform, 3821 Framing, 4221 Timber Solid Cladding* and *4222 Manufactured Timber Sheet Cladding*. To simplify modelling of reference buildings, all transport of timber is based on distances for *3821 Framing*. Transport for engineered woods is based on *3813 Engineered Wood Products,* except hybrid LVL (see below). For landfilling, see information provided for module C. <u>Engineered wood, post tensioned timber frame structure</u> Since the assumption is that the prefabrication of the hybrid LVL structural system is in Christchurch, transport from the prefabrication plant to Auckland, Wellington and Christchurch is assumed to be by truck using distances in the Distance-Mode Model in the module A4 datasheet. <u>Floors</u> Includes an estimate for galvanised steel nails fixings from NZS 3604:2011 *Timber-framed buildings* Table 7.5. Based on this, the mass of nails required for fastening 1 m^2 of softwood and hardwood timber floor is estimated as 0.077 kg (double nailed). Data representing galvanised nails has a zinc coating of 285 g/m^2, about 11% less than the 320 g/m^2 zinc coating set out in NZS 3604:2011. Lifting/moving of floors assumed to be by manual labour. <u>Biogenic carbon storage in timbers and engineered woods sourced from sustainable forestry operations</u> Where carbon dioxide sequestration has been previously accounted (in modules A1–A3), it is added back where the product leaves the system boundary, for example, as a waste which is reused or recycled. For a full illustration of the approach used to account for biogenic carbon storage, see Appendix C.

A3. Use stage (modules B2 maintenance and B4 replacement)

Maintenance (module B2) and replacement (module B4) are modelled according to data provided in the module B2 and B4 datasheets respectively. The data in these datasheets have been compiled according to the method set out in Dowdell et al. (2016).

Provided recommended maintenance is carried out as required by the manufacturer, an assumption is made that a material or product will reach its estimated service life without the need for repair. Upon reaching its estimated service life, the material or product is replaced with a like-for-like alternative.

Repair may also be required due to accidents or unforeseen, extreme events which are not considered.

A3.1 Maintenance

The main maintenance activity which applies to all materials and products external to the building is washing once a year, except for glazing which is washed four times a year. The calculated environmental indicators are based on provision of water from a reticulated system and assumes that all water used evaporates rather than drains to a wastewater system (meaning no account of treatment of wastewater is included). No account is taken of use of any detergents and other consumables, nor is the energy that may be required for accessing all parts of the enclosure. The amount of water used for washing is based on 1 L/m^2.

Washing is modelled based on recommended frequency to avoid accumulation of debris, salts etc. However, in practice, building owners may not wash the building enclosure as frequently as indicated, leading over time to a potential need to repair (module B3) or prematurely replace (module B4) some materials.

Specific information about materials and products, where relevant, is provided below.

A3.1.1 Membrane systems

Description	A small area of roof membrane systems requires application of patches as set out in the module B2 datasheet. This states that 1.5% of the membrane area is patched in each of years 15 to 19 inclusive after installation. Data used to represent these patches is based on product manufacture data (modules A1–A3) and transport & construction (modules A4–A5). The per year impact of application of patches is annualised by multiplying by the 5 years of application, and dividing by the 20 year estimated service life. The accumulation of patches is not considered when the product reaches the end of its service life and is replaced.

A3.1.2 Paint

Description	For the purposes of calculating impacts from painting needed for maintenance of materials and products, some materials/products may arrive at site having already received a factory applied paint finish and others may require painting at the construction site. Based on the module B2 datasheet, where a product has a factory applied coating, the period before first painting for maintenance is longer than if the material or product is first coated at the construction site. Clear coat and stain are not currently considered. Anodised aluminium does not require painting.

A3.1.3 Floor linings excluding timber (interior)

Description	<u>Carpet</u> Carpet EPDs (egetaepper a/s, 2016a, 2016b; Fletco Carpets A/S, 2014a, 2014b) provide scenarios for maintenance of carpets, which includes vacuum cleaning and washing. Since electricity and water use for these activities is included in plug loads in module B6 and water use in module B7 respectively, they are not separately calculated. Use of cleaning products not included.

Description	Vinyl (PVC) floor sheets The Karndean EPD (Karndean Design Flooring, 2016) provides a scenario for maintenance which involves dust mopping, damp mop/cleaner and spray buffing/restoration. These can involve use of water, detergent and electricity. Currently this is not included as plug loads are in module B6 and water use is in module B7.

A3.1.4 Services and infrastructure

Description	Vertical transport Maintenance of elevator data are taken directly from relevant EPDs. Some EPDs report zero values and it is not clear if this is a true zero (which seems unlikely) or reflects that maintenance is not reported. Despite this, where zero is reported, this is taken as a true zero. Where maintenance values are provided, they add 2–3% to reported greenhouse gas indicators.

A3.2 Replacement

Where a material or product requires replacement during the service life of a building, environmental indicators are calculated according to the following:

- Production of the material or product to replace the material or product that has reached its estimated service life. This is based on product stage impacts (modules A1–A3).
- Transport and installation in the building, based on the construction process (modules A4– 5).
- Waste management and end of life of the removed material or product, based on the end-of-life stage (modules C1–C4).

Any reuse, recycling or recovery of material generated because of replacement, may contribute towards module D benefits and loads beyond the system boundary.

Using estimated service life data in the module B4 datasheet, the number of replacements over the service life of the building is calculated using the formula in Section 9.3.3 of EN 15978, which is:

$NR(j) = E\,[ReqSL/ESL(j) - 1]$

where:

$E\,[ReqSL/ESL(j)]$ is rounded to the next higher integer.

$ESL(j)$ is the estimated service life for a product "j" (from the module B4 datasheet).

$NR(j)$ is the number of replacements.

ReqSL is the required service life of a building (the default is 60 years for New Zealand office buildings and 90 years for residential buildings unless otherwise defined in a client's brief, taken from the modules B1–B7 datasheet).

In some cases, where the remaining service life of the building is short in comparison with the estimated service life of a material or product, the number of replacements may be adjusted to reflect the actual likelihood of replacement.

Specific information about materials and products, where relevant, is provided below.

A3.2.1 Floor linings, excluding timber (interior)

Description	Carpet The module B4 datasheet contains no information on reference service life under *6511 Carpet finish to floors and walls*. Carpet EPDs (egetaepper a/s, 2016a, 2016b; Fletco Carpets A/S, 2014a, 2014b) report a minimum service life of 10 years, although the technical service life can be considerably longer. Service life is strongly dependent on correct installation and adherence to cleaning and maintenance instructions. An estimated service life of 10 years is therefore used.

Description	Vinyl (PVC) floor sheets The Karndean EPD (Karndean Design Flooring, 2016) provides a minimum service life of 10 years, although the technical service life can be longer. An estimated service life of 10 years is therefore used.

A3.2.2 Membrane systems

Description	When a roof membrane system has reached the end of its estimated service life and requires replacement, the assumption is that the existing membrane system is removed and the new membrane system is placed over it. In practice, this may happen or the new roofing layer may be applied on top of the old layer, depending on its condition. Also, plywood (if present) underneath could be inspected and some may be replaced, which is not considered here. For fibre reinforced bitumen membrane systems, the assumption is that each new layer is torched on (based on environmental indicators calculated for modules A4–A5). In practice however, one layer may be mechanically fixed on the old layer, and then another layer torched on that.

A3.2.3 Metals and metal-containing composites

Description	The estimated service life of galvanised and Colorsteel® products in external applications is based on the exposure zone in which they are used, derived from the module B4 datasheet (available at www.branz.co.nz/buildinglca and select "Data".

A3.2.4 Services and infrastructure

Description	Vertical transport Designed reference service life data provided in EPDs provides the basis for defining replacement. This varies from 20 to 25 years depending on the elevator.

A4. End-of-life stage (modules C1–C4)

Quantities of materials and products that are reused, recycled or recovered during building demolition/deconstruction are based on the module C1 datasheet, available at www.branz.co.nz/buildinglca (and select "Data"). This includes a description of the likely end-of-life route.

Energy required to deconstruct buildings is accounted for structural materials such as concrete, timber and engineered wood (except plywood) and steel using data from the

Athena Sustainable Materials Institute (M Gordon Engineering, 1997), which includes a demolition analysis for buildings with a wood, steel and concrete structures. The wood and steel structural systems additionally include use of concrete, for which the energy for demolition is separated.

Using the data in this report, the following tables summarise the analysis that has been undertaken and the resulting demolition energy that has been calculated.

Table 11. Demolition energy for a wood structure from M Gordon Engineering (1997) Table B1.

Material	Mass (kg)	Energy (MJ)	MJ/kg	Notes
Concrete	1040628	209647	0.2015	Above grade
	158203	11362	0.07182	Below grade
	1198831	58082	0.0484	Stockpiling, loading and transport to offsite Municipal Recycling Facility (MRF)
Wood	107096	192998	1.8021	Total wood
	107096	66461	0.6206	Stockpiling, loading and wood chipping for transport to offsite MRF
GRAND TOTAL:	1305927	546895	0.4188	

Table 12. Demolition energy for a steel structure from M Gordon Engineering (1997) Table B3.

Material	Mass (kg)	Energy (MJ)	MJ/kg	Notes
Concrete	1384732	329065	0.2376	Above grade
	158203	11362	0.0718	Below grade
	1542935	70739	0.0458	Stockpiling, loading and transport to offsite MRF
Steel	150978	54185	0.3589	Total steel
	150978	34478	0.2284	Steel preparation, loading and transportation
GRAND TOTAL:	1693913	509605	0.3008	

Table 13. Demolition energy for a concrete structure from M Gordon Engineering (1997) Table B5.

Material	Mass (kg)	Energy (MJ)	MJ/kg	Notes
Concrete	596122	73032	0.1225	Above grade
	158203	11351	0.0718	Below grade
	2935198	169013	0.0576	Above ground horizontal
	700348	43961	0.0628	Above ground vertical
	79636	7006	0.0880	Miscellaneous
	4469475	165378	0.0370	Concrete stockpiling, loading, transport to offsite MRF
	4469477	477886	0.1069	

Table 14. Summary of demolition energy by structural material.

	Total mass (kg)	Energy (MJ)	MJ/kg
Concrete	14422514	1159998	0.080
Wood	214192	259459	1.211
Steel	301956	88663	0.294

Energy per kg figures in the summary table above have been used. The energy is assumed to be supplied by combustion of diesel.

Specific information about materials and products, where relevant, is provided below. Where no specific information is provided, the approach set out in this section is applied.

A4.1 Aggregates

Description	Reused material assumed to remain on site, and therefore has reached its end-of-waste state. Other material is excavated. For energy use arising from excavation, see *Aggregates* in modules A4–A5.

A4.2 Concrete

Description	For the proportion of concrete (block (and grout), in situ, precast and mortar) that is crushed for secondary aggregate, the assumption is that a mobile diesel-powered concrete crushing plant is brought to site. Data for energy required by concrete crushers sourced from Wilburn and Goonan (1998). Concrete crushers may also be electrically powered but more likely that a mobile plant is diesel powered. Data do not consider transport of the concrete crusher to the site and wear and tear on equipment. Energy from diesel required to recover reinforcement from concrete based on EcoInvent data. The amount of reinforcement that is recovered is determined by the proportion of concrete that is crushed for aggregate. Crushed concrete assumed to reach its end-of-waste state once sorted and graded for sale. Onward transport is therefore excluded. Carbonation is not included.

A4.3 Floor coverings

Description	<u>Carpets</u> All carpet assumed to go to landfill. Impacts taken from 100% landfill scenario in carpet EPDs (egetaepper a/s, 2016a, 2016b; Fletco Carpets A/S, 2014a, 2014b).

Description	<u>Vinyl flooring</u> All vinyl flooring goes to landfill (Karndean Design Flooring, 2016).

A4.4 Insulation

Description	Reused material is assumed to reach its end-of-waste state on removal from the building. No onward transport is considered.

	Vacuum insulation panels The Dow Corning Corporation EPD (Dow Corning Corporation, 2013) indicates that parts of the product can be recycled and recovered at end of life in Europe. It is assumed that this does not occur in New Zealand, and all product is landfilled at its end of life.

A4.5 Membrane systems

Description	Accumulation of patches applied due to maintenance (module B2) are not considered, as the mass added is insignificant in comparison with replacement. Modelling of landfilling based on constituent materials.

A4.6 Metals and metal-containing composites

Description	Aluminium Scrap preparation based on EcoInvent data "RoW: treatment of aluminium scrap, post-consumer, by collecting, sorting, cleaning, pressing" with the following adjustments: The original data shows a loss rate of 20% by mass of aluminium. This has been adjusted to 25% in line with data in the module C1 datasheet. All inputs and outputs are assumed to show a linear relationship with scrap input and were pro-rated accordingly. Use of NZ grid electricity (medium voltage). Scrap transported (assumed to travel 5000 km to Australia). Some scrap aluminium is remelted in NZ (by MCK) but it is assumed that the process would not take scrap aluminium from building demolition in large volumes, so this is not specifically considered. Aluminium that is not recycled is landfilled. The end-of-waste state of the aluminium for recycling is reached following processing (cleaning, shredding, pressing etc) and transport to a remelt facility. Steel Where differences arise in the recycling scenario declared in EPDs e.g. (BlueScope Steel Limited, 2015; Pacific Steel, 2018), and the recycling rate in the module C1 datasheet, the rate in the module C1 datasheet is used. Deconstruction energy based on analysis of "Steel – Recycle Case" (Table B1, B3, B5, (M Gordon Engineering, 1997) and includes site mobilisation and set up, removal of steel elements using a Caterpillar with hydraulic shear (for selective cutting and pulling), cutting of dislodged steel into smaller sections for loading onto a truck. Cut sections loaded using an excavator with a grapple. This is only applied for structural elements. Recycled steel is transported overseas (Australia assumed, with a transport distance of 5000 km based on Distance Mode model in the module A4 datasheet) EcoInvent data used to model module C1 (deconstruction/demolition) and C2 (transport) impacts. Impacts arising from C3 waste processing and C4 landfill are based on data provided in relevant EPDs (where available), such as BlueScope Steel (BlueScope) and Pacific Steel (2018). Figures for C3 in the EPD are based on a recycling rate of 89%. These are pro-rated for the recycling rate in the module C1 datasheet. Similarly, figures for C4 in the EPD are based on a landfill rate of 11%. These are pro-rated for the landfill rate in the module C datasheet.

	Module C4 impacts based relevant EPDs (see above) are similar to those stated in an EPD published by the European Association for Panels and Profiles (2013). The end-of-waste state of the steel for recycling is reached following transport and processing, in accordance with relevant EPDs (see above). The end-of-waste state for reused steel is at the deconstruction site.

A4.7 Plasterboard

Description	No data found for environmental impacts arising from disposal of plasterboard to landfill. Modelling is therefore an estimate that includes transport to a landfill site and impacts associated with main constituents of plasterboard. Composition % based on thresholds in GIB Material Safety Data Sheet, as follows: Gypsum 65% (SDS states <70%). Inert filler 21% (SDS states <25%). Paper 12% (SDS states <15%) Starch 2% (SDS states <3%). For simplicity, starch and paper added together. EcoInvent datasets used cover impacts of waste gypsum, inert waste and graphical paper in a sanitary landfill, using EcoInvent "Rest of the World" datasets (except gypsum, which is based on Swiss data).

A4.8 Services and infrastructure

Description	<u>Vertical transport</u> Figures for end of life taken from relevant EPDs. <u>Energy generation</u> Photovoltaic panels treated as inert waste due to lack of data.

A4.9 Timber and engineered wood

Description	**Landfilling:** <u>Engineered Wood</u> Impacts arising from landfilling are based on the "Typical" scenarios in relevant EPDs, for example, published by the FWPA for glulam and plywood (Forest and Wood Products Australia Limited, 2017a). These are based on a Degradable Organic Fraction (DOCf). For example for plywood, this is 1.4% from bioreactor experiments on solid wood (Forest and Wood Products Australia Limited, 2017c) and "can be considered as an upper limit for degradation of carbon in solid timber placed in landfill". Carbon balances for timber and engineered woods (from sustainable forestry) are provided in Appendix C. <u>Timber</u> Impacts arising from landfilling are based on the "Typical" scenario in an FWPA EPD (Forest and Wood Products Australia Limited, 2015c). These are based on a Degradable Organic Fraction (DOCf) of 0.1% from bioreactor experiments on *radiata* pine. From the FWPA EPDs, for every kg of carbon converted to landfill gas, 71.2% is released as carbon dioxide and 28.8% is released as methane. No data specifically assessing greenhouse gas emissions from NZ landfills because of disposed timber products could be found. However, "typical"

	landfill emissions have been selected over "NGA" figures from the FWPA EPDs because: • By experiment, engineered wood products excavated from landfill have been found to produce little or no landfill gas (Wang et al., 2011; Ximenes et al., 2013). • The prevalence of treated timber in New Zealand, which has been found to degrade extremely slowly in landfill conditions (Keene and Smythe, 2009). The report also states that "untreated timber will store carbon for a prolonged period while slowly decaying". • The "typical" values are for solid timber whereas "NGA" (Australia National Greenhouse Accounts) values are based on wood tree branches ground to a fine powder under anaerobic conditions. It is highly unlikely that timber disposed to landfill will be in a powder form. • EcoInvent 3.1 data "CH: treatment of waste wood, untreated, sanitary landfill" provides greenhouse gas emissions per kg disposed that are in reasonable agreement with "typical" figures. The effect of this selection is significant in that landfill gas greenhouse gas emissions over 100 years are 0.111 kg CO_2 eq./kg, instead of 1.36 kg CO_2 eq./kg (for dressed, kiln dried softwood), comprising only 8% of "NGA" values. This compares with Wood for Good (www.woodforgood.com), which reports higher emissions of 1.8 kg CO_2 eq/kg based on an organic carbon conversion of 38.5% for UK emissions. Building level results should, ideally, be tested for their sensitivity to use of these values, especially for buildings with greater use of timber and/or engineered wood. A carbon balance for timber and engineered woods (from sustainable forestry) are provided in Appendix C. <u>Hybrid LVL</u> It is assumed that the steel in the hybrid LVL system is separated for recycling at the building end of life. The energy required for separating is based on the same data for separation of steel from concrete (from EcoInvent 3.1). All the LVL is assumed to go to landfill. **Reuse/Recycling/Recovery** Any product that is reused or recycled is assumed to reach the end-of-waste state after deconstruction and before any onward transport and processing. Sequestered biogenic carbon associated with components for reuse, materials for recycling or for energy recovery, is added to the calculated greenhouse gas impact of the module in which the material reaches the end-of-waste state. This ensures that the carbon benefit of reusing, recycling or obtaining energy from timber can be accounted in module D without double counting. For example, 1 kg of wood manufactured in modules A1–A3 includes the sequestering of 1.6 kg of biogenic carbon dioxide arising from the growth cycle of the tree (in a sustainable forestry operation) supplying the wood. If 25% of that wood is recycled at end-of-life, the biogenic carbon associated with the material leaving the product system is added back (amounting to 0.25 * 1.6 = 0.04 kg biogenic carbon dioxide). The biogenic carbon dioxide sequestration can therefore be considered in the next product system in which the recycled material is used (reflected in module D).

	A carbon balance for timber and engineered woods (from sustainable forestry) are provided in Appendix C.

A5. Supplementary information beyond the building life cycle (module D)

Module D information for materials is organised as the total of environmental benefits and loads beyond the building life cycle that may be accrued through use of the material in a building, divided according to the following categories:

- Reuse (RU).
- Cascade recycling (CR).
- Energy recovery (ER).
- Material recycling (MR).

For the purposes of calculating benefits, the definition of the "end-of-waste state" needs to be defined. For materials that reach the "end-of-waste state" on disposal at the construction site (for example, for materials that have a scrap value), the environmental impacts of onward transport and processing are accounted in module D. For materials that require further processing and/or transport before reaching their "end-of-waste state", the environmental impacts of this further processing and/or transport are accounted for in the module in which the material becomes waste (for example, module A5 if wasted at the construction site, module B4 if replaced during the life of the building or module C during building demolition or deconstruction).

The definition of the "end-of-waste state" used to calculate environmental indicators is provided for individual materials and products in the sections preceding this one.

Having defined the "end-of-waste state", the calculation of any environmental benefits or loads beyond the life cycle of the building being considered is interpreted as follows:

- **Reuse (RU)** – The benefit is taken as the environmental impacts arising from the manufacture of the same product (provided in modules A1–A3). Any assumptions or limitations of data applied in modules A1–A3 are similarly applied here. This may also include the benefit of avoidance of ship transport for imported product.
- **Cascade recycling (CR)** – This refers to "closed loop" recycling in which a product may be recycled to produce a product with the same properties and capable of fulfilling the same function or a different function (with further processing). This primarily concerns metals.

The benefit of recycling is calculated as follows:

1. The mass of material that is collected for recycling less the recycled content of the collected material. For example, for a steel manufactured with a scrap input of 10% for which 70% is recovered at the building end of life (module C1), the benefit of recycling per kg is applied to 0.6 kg (0.7 kg – 0.1 kg).
2. For the proportion of the collected material that has come from primary production, the environmental impact of processing the collected material and substitution of primary production. For aluminium, primary production to aluminium billet is considered. For steel, production of pig iron is considered.

Calculation of the benefit or load is as set out in Appendix D of the ALCAS document *Requirements for the development of AusLCI datasets* (AusLCI Committee, 2014).

- **Energy recovery (ER)** – this applies to the materials *Timber Softwood, Dressed Kiln-Dried* and *Timber Hardwood, Dressed Kiln-Dried.* For material collected which is used for energy recovery, the environmental impact of producing heat is calculated using the EcoInvent 3.1 dataset "heat production, wood chips from post-consumer wood, at furnace 300 kW". The benefit is calculated by subtracting the production of heat using natural gas. This is based on the EcoInvent 3.1 dataset "heat production, natural gas, at industrial furnace >100 kW" adapted to include use of New Zealand low voltage grid electricity, and natural gas exploration, extraction, production and distribution (Sacayon Madrigal, 2015).
- **Material recycling (MR) –** Materials may be "downcycled" to fulfil a different purpose from the purpose for which they were used originally. For example, crushing of concrete to produce (secondary) aggregate. The benefit of material recycling is calculated as the production of material that fulfils the same purpose as the secondary product arising from the recycling process. In the concrete example, the benefit is calculated as the environmental impacts arising from quarrying of primary aggregate (which would be necessary if the concrete was not recycled).

Similarly, waste material may be cut into smaller pieces and used for filling gaps, for example use of offcuts of timber. In this case, the benefit of using the material has been calculated as substitution of new product (the same as reuse).

Specific information about materials and products, where relevant, is provided below. Where no specific information is provided, the approach set out in this section is applied.

A5.1 Aggregates

Description	The benefit beyond the system boundary of reuse is the substitution of quarrying of primary material. Reused material is assumed to provide the same properties as quarried material and is therefore treated as a 1:1 replacement. Module D benefits are therefore modelled as quarrying of an equivalent mass of material (based on data for modules A1–A3 for *Sand* and *Granular Fill*.

A5.2 Concrete

Description	<u>Unreinforced and reinforced concrete</u> Waste arises from: Overordering of concrete at construction sites, a proportion of which is washed to recover aggregates (comprising half the mass of the washed concrete). Rates provided in the module A5 datasheet. Deconstruction/demolition of the building at its end of life. A proportion of the concrete is crushed for secondary aggregate. Rates provided in the module C datasheet. The waste material does not reach the "end-of-waste" state until after washing in (1) above or crushing in (2) above. The impacts of these activities are therefore accounted within the building life cycle. Aggregate obtained through either washing of wet concrete or crushing of cured concrete, substitutes quarrying of primary aggregate. A 1:1 replacement is assumed. Benefit of substituted quarried aggregate represented by modules A1–A3 data for *Sand*.

	Reinforcement that becomes available in module C is recycled. The benefit of this is based on values provided in Pacific Steel (2018), modified according to recycling rate in the module C1 datasheet. Mortar Mortar is associated with bricks, a proportion of which are crushed to produce secondary aggregate at the building end of life. The proportion of bricks (and mortar) that is diverted from cleanfill is based on the module C1 datasheet. Benefit of substituted quarried aggregate represented by modules A1–A3 data for *Sand*.

A5.3 Fibre cement

Description	Waste rates and end of life routes as provided in the module A5 and module C datasheets. Reuse provides a module D benefit being the avoidance of manufacture, based on modules A1–A3 data. Any impacts due to transport and storage of panels for reuse not considered, nor is any saving in long distance transport due to avoidance of need to import from overseas.

A5.4 Metals and metal-containing composites

Description	The "end-of-waste state" for metals is reached on disposal at the construction site (module A5) and after processing (for example, separation, baling) in module C1. Aluminium For the calculation of Cascade Recycling benefits, modelled as the impacts of an aluminium refining process that takes aluminium scrap and makes aluminium ingot, less production of primary ingot on a 1 for 1 basis. EcoInvent 3.1 data used, being the impacts of "Treatment of aluminium scrap, new, at refiner" less the impacts of aluminium production described in modules A1–A3 (which are based on data from World Aluminium (2013). Recycling of scrap aluminium begins with reception of scrap and ends with production of aluminium billets. The dataset excludes salt slag processing and dross recycling, as well as an output of unspecified metal for recycling output. Primary production includes unloading of process material, pre-treatment of hot metal, recovery and handling of internal process scrap, batching, metal treatment and casting operations, homogenising, sawing and packaging activities, maintenance and repair of plant and equipment, treatment of process air, liquids and solids and production of infrastructure (based on estimate). Galvanised steel For the calculation of Cascade Recycling benefits, modelled as the impacts of steel billet production (low alloyed) in an electric arc furnace less production of low alloyed steel billet via a blast furnace route. The per kg greenhouse gas benefit is 1.57 kg CO_2 eq./kg. The benefit does not include the input of scrap in modules A1–A3 which is 10%.

	Structural steel The BlueScope Steel EPD (BlueScope Steel Limited, 2015) shows a module D benefit for greenhouse gases of -1.22 kg CO_2 eq, which is derived from an end of life recycling rate of 89% and a scrap input of 8.5% post-consumer and 6.5% pre-consumer waste. Therefore, per kg of steel collected for recycling, the benefit is -1.22/(0.89-0.15) = -1.65 kg CO_2 eq./kg scrap. This is applied to the amount of steel that becomes available as scrap. Colorsteel® products The New Zealand Steel EPD (2018) shows a module D benefit for Endura® and Maxx® that varies with product and thickness. For example, the module D benefit of recycling Colorsteel® Endura® with a BMT of 0.55 mm is -5.48 kg CO_2 eq./m^2 based on a recycling scenario of 89%. This benefit is pro-rated according to the recycling rate in the module C1 datasheet. Pacific Steel products The Pacific Steel EPD (2018) shows a module D benefit of -1.29 kg CO_2 eq./kg based on a recycling scenario of 89%. This benefit is pro-rated according to the recycling rate in the module C1 datasheet.

A5.5 Plasterboard

Description	The “end-of-waste state” is reached following crushing. For Material Recycling, crushed gypsum from waste plasterboard may be used as a soil conditioner. No data are available to quantify this benefit and therefore it is currently omitted.

A5.6 Timber and engineered wood

Description	The modules A1–A3 greenhouse gas impact of most timber products is negative, reflecting the sequestering of biogenic carbon dioxide by growing trees that comprise the product. Material that leaves the product system for application in another product system (through reuse, recycling or for energy recovery) carries with it the sequestered biogenic carbon dioxide (which is added back in the module in which the material reaches its end-of-waste state). This is in line with Section 6.4.3.2 of EN 15804 and Figure 1 of EN 16485. The sequestered biogenic carbon dioxide associated with the timber or engineered wood product is therefore available in the next product system in which the material is used, reflected in module D.

Appendix B: Energy and water modelling

This section provides information on the source and derivation of calculated indicator values for non-material data. It is divided into the following sections:

- Section B1: Use stage (module B6 operational energy)
- Section B2: Use stage (module B7 operational water)

B1. Use stage (module B6 operational energy)

In LCAQuick v3.4, operational energy can be obtained from grid electricity, electricity generated from use of photovoltaic panels (PV), or combustion of fuels.

B1.1 Electricity

Electricity is obtained either from the grid or from on-site generation using PV. Grid electricity supply and distribution is modelled as follows:

	Grid electricity (low voltage) delivered to a building
Description	Underlying LCA model developed by Sacayon Madrigal (2015) which is used to calculate annual average impact factors (including transmission and distribution) for different sources of energy supplying the New Zealand grid. These are applied according to the fuel mix comprising the Mixed Renewables scenario from 2020 to 2050 in *electricity-demand-generation-scenarios-summary-2016-results.xlsx*[24], which accompanies (MBIE, 2016). From this report, "the Mixed Renewables scenario has a mixture of geothermal and wind plant built, starting in 2010. This scenario assumes an average of 1% annual electricity demand growth, reflecting moderate GDP and population growth, and current views on relative technology cost and expected fuel and carbon prices." Beyond 2050, the fuel mix supplying the grid in 2050 continues to be applied for the rest of the building service life.
Platform/source(s) of data	EcoInvent 3.1, adapted/MBIE, 2015).
Data characteristics	Sacayon Madrigal, 2015
Age	Represents net electricity generation delivered (and sources of supply) each year from 2020 to 2050.
Technology coverage	Includes electricity generation from technologies including wind turbines, geothermal, hydroelectric, solar, coal and gas combustion. Includes transmission and distribution.
Geographical coverage	New Zealand in terms of net generation and sources. Underlying model uses EcoInvent 3.1 data, adapted in part where NZ-specific data available. See Sacayon Madrigal, 2015.
Assumptions	Sacayon Madrigal, 2015
Completeness/ exclusions	Sacayon Madrigal, 2015
Plausibility check	In terms of combustion-related greenhouse gas emissions from fossil fuels, and fugitive emissions from geothermal, the Sacayon Madrigal model and MfE corporate greenhouse gas emissions factors are the same.

[24] Available at www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-modelling/electricity-demand-and-generation-scenarios/

	However, the Sacayon Madrigal model additionally includes pre-combustion emissions from fossil fuels (exploration, extraction, transport and processing of fossil fuels prior to combustion), biogenic methane emissions from hydroelectric schemes and infrastructure. Based on the Sacayon Madrigal model using the Mixed Renewables scenario and starting in 2020 for a 90 year period (and extrapolating beyond 2050 using the fuel mix supplying the grid in 2050), the calculated annualised grid emission factor is 0.128 kg CO_2 eq./kWh. Starting in 2020 for a 60 year period, the calculated annualised grid emission factor is 0.129 kg CO_2 eq./kWh. A further master's level research project at Massey University to investigate the New Zealand grid and associated environmental impacts is due to finish mid-2020.
Consistency (e.g. with EN 15804)	Sacayon Madrigal, 2015

Where on-site PV is incorporated in a building design, the user provides an estimate of the annual electricity generated by the PV (for example, using the BRANZ Photovoltaic Generation Calculator Tool available under "Toolbox" at www.branz.co.nz).

The environmental impacts arising from manufacture of PV (including mounting) is accounted for in modules A1–A3. The environmental impacts associated with in-use generation of electricity are taken as zero for PV in module B6.

B1.2 Combustion of fuels

Provision of heat is provided from combustion of the following fuels in LCAQuick v3.4 (in addition to electricity). Further information for each is provided below.

- Natural gas.
- Wood (mixed logs).
- Landfill gas (for Christchurch).

B1.2.1 Natural gas (offices)

Natural gas combustion is represented using the EcoInvent 3.1 dataset entitled "heat production, natural gas, at boiler, fan burner non-modulating < 100 kW". In addition to combustion-related emissions, the data include pre-combustion (extraction of gas, transport, processing, infrastructure) and use of grid electricity drawn from the work of Sacayon Madrigal (Sacayon Madrigal, 2015).

Environmental impacts per kWh are provided based on gas recorded at the meter rather than per kWh of heat supplied. Therefore, in LCAQuick v3.4 natural gas use in office buildings requires an input of kWh of natural gas consumed (at the meter) from energy modelling / simulation.

B1.2.2 Natural gas (residential)

When modelling residential buildings, the kWh input required in LCAQuick v3.4 is on a heat delivered basis, rather than at the meter. In addition to combustion-related emissions, the data include pre-combustion (extraction of gas, transport, processing, infrastructure) and use of grid electricity drawn from the work of Sacayon Madrigal (2015).

The greenhouse gas impact is 0.231 kg CO_2 eq./kWh of which the combustion only component is 0.213 kg CO_2 eq./kWh. This has good agreement with EECA data, which provides a combustion only greenhouse gas emission factor of 59 kg CO_2 eq./GJ for a natural gas condensing combination boiler (post 1997) with auto-ignition[25]. On a per kWh basis, this equates to 0.2124 kg CO_2 eq.

B1.2.3 Wood (mixed logs)

Data representing combustion of mixed logs in a wood burner taken from EcoInvent 3.1 dataset entitled "heat production, mixed logs, at wood heater 6kW, state-of-the-art 2014". The greenhouse gas impact factor per kWh heat delivered includes release of sequestered carbon dioxide. The data include start – stop and part-load operation (which reduces efficiency and increases emissions), as well as the physical infrastructure (wood burner and flue). The resulting figure is higher than other figures, for example, MfE provide 0.067 kg CO_2 eq./kg wood. At 10% moisture content the lower heat value is 17.2 MJ (Eng et al., 2008), which provides a greenhouse gas emission factor of 0.014 kg CO_2 eq./kWh.

Additionally, transport of the wood is included, assuming a 100 km one-way journey to cover all transport from source of wood to merchant to customer using a small truck (3.5–7 tonne, Euro 4).

No data could be found to support a transport distance, and this is likely to be dependent on region. According to a Department of Conservation source,[26] less than a third, 27.7% of domestic consumers purchased their fuel (wood), the rest is obtained from free sources – most often their own or others' properties.

Nationally, 81% of wood purchasers were urban dwellers.[26] For these consumers, the transport distance for delivery of wood is likely to be longer.

Thus, the transport distance assumed, which adds almost 30% to the greenhouse gas emission factor used per kWh, may be considered as high and more indicative of a user in an urban environment. This is likely to be highly variable and will depend on specific circumstances.

B1.2.4 Landfill gas (Christchurch)

In Christchurch, potential use of landfill gas supplied from the Burwood Landfill Gas Utilisation Project is built into LCAQuick v3.4. Landfill gas combustion is represented using the EcoInvent 3.1 dataset entitled "heat and power co-generation, biogas, gas engine". Environmental impacts are expressed per kWh of landfill gas measured at the meter and assume that the boiler efficiency is the same as used for natural gas.

Additionally, the benefit of using landfill gas is represented in module D as substitution of LPG, represented by production and combustion of propane.[27]

Impact factors per kWh are based on heat supplied.

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[25] Taken from "Book2 – EECA fuel combustion GHG figures.xlsx".
[26] www.doc.govt.nz/Documents/science-and-technical/casn114a.pdf
[27] EN 15978 does not provide detail concerning use of module D in this way. Since the Burwood Landfill Gas Utilisation Project was established as an approved emission reduction project under the MfE "Projects to reduce Emissions" (PRE) programme, it was decided to represent this benefit through substitution of LPG (which would be the likely source of heat).

B2. Use stage (module B7 operational water)

WaterCare[28] information for Auckland shows a variety of treatment methods are used for Auckland's tap water supply, including ultrafiltration for water taken from the Waikato River. However, most treatment plants appear to be conventional, and this is assumed for the rest of New Zealand. Environmental impacts associated with tap water supply are therefore based on the EcoInvent 3.1 RoW dataset entitled "tap water production, conventional treatment" with inclusion of use of New Zealand grid electricity.

Environmental indicators for wastewater treatment are based on the EcoInvent 3.1 RoW dataset entitled "treatment of wastewater, average, capacity 1.1E10l/year" with inclusion of use of New Zealand grid electricity.

For simplicity, wastewater volume generated during building occupation is assumed to be the same as tap water demand.

[28] www.watercare.co.nz/about-watercare/our-services/water-treatment/Pages/default.aspx

Appendix C: Timber and engineered wood – approach to calculating climate change impact and resulting life cycle carbon balance

C1. Approach to calculating climate change impact

Environmental impacts are provided for timber and engineered wood sourced:

- From sustainable forest management practices.
- From unsustainable forest management practices, don't know or won't ensure from sustainable forestry.

The New Zealand Forests Act 1949 defines sustainable forest management as "management of an area of indigenous forests land in a way that maintains the ability of the forest on that land to continue to provide a full range of products and amenities in perpetuity while maintaining the forest's natural values.

Another definition is "stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems"[29].

The "unsustainable forest management" category is meant to encompass situations where processes are not put in place to ensure that timber and engineered woods procured for a build can be traced back to a source of supply which uses sustainable forest management practices. Additionally, where effort will not be put into ensuring these products come from sustainable forestry, or there is uncertainty, then impact factors for "from unsustainable forest management practices, don't know or won't ensure from sustainable forestry" should be used.

Only where effort will be made to ensure timber and engineered wood products are procured from sustainable forestry, and this will be able to be demonstrated (for example, through a chain of custody), should timber and engineered woods in the category "from sustainable forest management practices" be used.

Examples of chain of custody schemes include the Forestry Stewardship Council (https://nz.fsc.org/en-nz) and the Programme for the Endorsement of Forest Certification (www.pefc.org/).

Where timber and engineered woods are from sustainable sources:

- The uptake of atmospheric carbon dioxide by the growing tree is included in the modules A1–A3 climate change impact. Calculation of the biogenic carbon content in these products is based on EN 16449.
- The characterisation of biogenic carbon fluxes is calculated using Figure 1 of EN 16485, which considers cases where carbon neutrality can be assumed.

Where the source of timber and engineered woods is from unsustainable forestry management practices, or the source is not known, or no effort will go into ensuring it

[29] www.pefc.org/what-we-do/our-approach/what-is-sustainable-forest-management

is from sustainable forestry, then the characterisation of biogenic carbon fluxes is calculated using Figure 2 of EN 16485, which considers cases where carbon neutrality cannot be assumed.

Currently, the greenhouse gas impact of timber and engineered woods from unsustainable forestry management practices do not consider additional sources of greenhouse gases such as changes to soil carbon. These are therefore likely to under-report the greenhouse gas emissions.

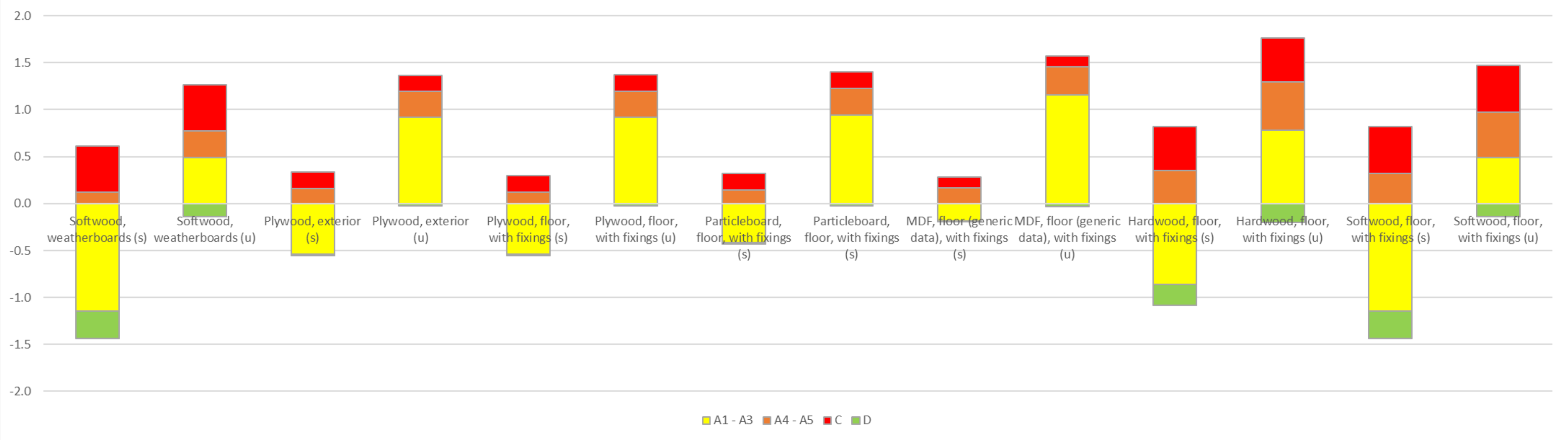
Figure 11 and Figure 12 summarise the greenhouse gas impacts of timber and engineered woods (for structural and non-structural applications) by building life cycle stages. Results are not presented for module B2 (maintenance) and module B4 (replacement) in these tables as the impacts will vary depending on the service life of the building in which they are used. Points to note from these figures are:

- The modules A1–A3 climate change impact of the timber and engineered woods sourced from sustainable forest management practices is negative. This is a net figure which reflects greenhouse gas emissions arising from forestry, felling, transport and processing less the sequestration of atmospheric carbon dioxide by the growing tree prior to felling.
- The modules A4–A5 climate change impact of timber and engineered woods from unsustainable forest management practices are higher than for the equivalent products from sustainable forest management practices. Module A5 includes wastage at the construction site. The manufacture of product that becomes waste during construction is accounted in module A5. Therefore, this includes some manufacture which, for sustainably sourced product, will be negative (due to carbon dioxide sequestration), and for unsustainably sourced product, will be positive.
- Module A5 for floor products includes manufacture of galvanised steel fixings, so modules A4–A5 climate change impact is slightly higher.
- Modules C1–C4 climate change impacts for structural timbers and engineered woods are higher than for non-structural timbers and engineered woods, due to the allocation of demolition energy to structural materials as set out in Section A.4.
- Modules C1–C4 climate change impacts for softwood is higher as a greater proportion of the material is reused, recycled and recovered, compared to the engineered woods. The increased values for softwood therefore represent the additional processing needed, for example, to produce woodchips for energy recovery, and transport for reuse, recycling and recovery. The sequestered carbon dioxide for which the benefit is reflected in modules A1–A3 is also added back as the material leaves the system boundary. Since a greater proportion of the softwood leaves the system boundary for reuse, recycling or recovery, a greater amount of sequestered carbon dioxide is added back (see Section C2 for more information).
- Module D shows a larger benefit for softwood timber compared to engineered woods. This reflects the greater amount of softwood timber that is reused, recycled or recovered. For assumed rates, see the module A5 and module C1 datasheets available under “Data” at www.branz.co.nz/buildinglca.
- The post-tensioned system has a slightly higher module D benefit than glulam, LVL, CLT and I-joists. This is due to recycling of steel.
- No glulam, CLT, LVL or I-joists are assumed to be recycled at the building end-of-life (modules C1–C4).

Figure 11. Greenhouse gas impact by life cycle stages for timber and engineered wood structural materials (per kg).

Softwood sections (s)	Timber, soft wood, dressed kiln-dried sections [from sustainable forest management practices]
Softwood sections (u)	Timber, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Softwood wall framing (s)	Timber wall framing, soft wood, dressed kiln-dried sections [from sustainable forest management practices]
Softwood wall framing (u)	Timber wall framing, soft wood, dressed kiln-dried sections [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Softwood, framing, interior (s)	Timber structural framing, soft wood, dressed kiln-dried, interior use [from sustainable forest management practices]
Softwood, framing, interior (u)	Timber structural framing, soft wood, dressed kiln-dried, interior use [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Softwood, framing, exterior (s)	Timber structural framing, soft wood, dressed kiln-dried, exterior use [from sustainable forest management practices]
Softwood, framing, exterior (u)	Timber structural framing, soft wood, dressed kiln-dried, exterior use [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Glulam (s)	Engineered wood, glued laminated timber (Glulam, softwood) [from sustainable forest management practices]
Glulam (u)	Engineered wood, glued laminated timber (Glulam, softwood) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
CLT (s)	Engineered wood, cross laminated timber (CLT) [from sustainable forest management practices]
CLT (u)	Engineered wood, cross laminated timber (CLT) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
LVL (s)	Engineered wood, laminated veneer lumber (LVL) [from sustainable forest management practices]
LVL (u)	Engineered wood, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Post tensioned LVL (s)	Post tensioned timber frame structure, laminated veneer lumber (LVL) [from sustainable forest management practices], inc. steel reinforcing
Post tensioned LVL (u)	Post tensioned timber frame structure, laminated veneer lumber (LVL) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], inc. steel reinforcing
I-joist 200x45 (s)	Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices]
I-joist 200x45 (u)	Engineered wood, I-joist profile, 200x45 [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]

Figure 12. Greenhouse gas impact by life cycle stages for timber and engineered wood non-structural materials (per kg).



Softwood, weatherboards (s)	Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from sustainable forest management practices]
Softwood, weatherboards (u)	Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Plywood, exterior (s)	Engineered wood, plywood (exterior, A-bond) [from sustainable forest management practices]
Plywood, exterior (u)	Engineered wood, plywood (exterior, A-bond) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]
Plywood, floor, with fixings (s)	Plywood (A bond, floor) [from sustainable forest management practices], with galvanised fixings
Plywood, floor, with fixings (u)	Plywood (A bond, floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
Particleboard, floor, with fixings (s)	Particleboard (floor) [from sustainable forest management practices], with galvanised fixings
Particleboard, floor, with fixings (s)	Particleboard (floor) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
MDF, floor (generic data), with fixings (s)	MDF floor [from sustainable forest management practices], with galvanised fixings (generic)
MDF, floor (generic data), with fixings (u)	MDF floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings (generic)
Hardwood, floor, with fixings (s)	Hardwood (dressed, kiln dried) floor [from sustainable forest management practices], with galvanised fixings
Hardwood, floor, with fixings (u)	Hardwood (dressed, kiln dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings
Softwood, floor, with fixings (s)	Softwood (dressed, kiln dried) floor [from sustainable forest management practices], with galvanised fixings
Softwood, floor, with fixings (u)	Softwood (dressed, kiln dried) floor [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], with galvanised fixings

C2. Sequestered carbon dioxide

In this section, the sequestration of atmospheric carbon dioxide (mainly in module A1) in trees grown in sustainably managed forestry operations, and subsequent emission or storage of sequestered carbon dioxide through modules A4–A5, C1–C4 and D is summarised in the diagrams below for 1 kg of product.

Module B4 is omitted as this is dependent on how the timber or engineered wood product is used in a building, and the number of times in this application it needs to be replaced during the estimated building service life. Each time a product is replaced in module B4, this is a replication of the sum of modules A1–A3, A4–A5, C1–C4 and D.

Sequestered carbon dioxide may:

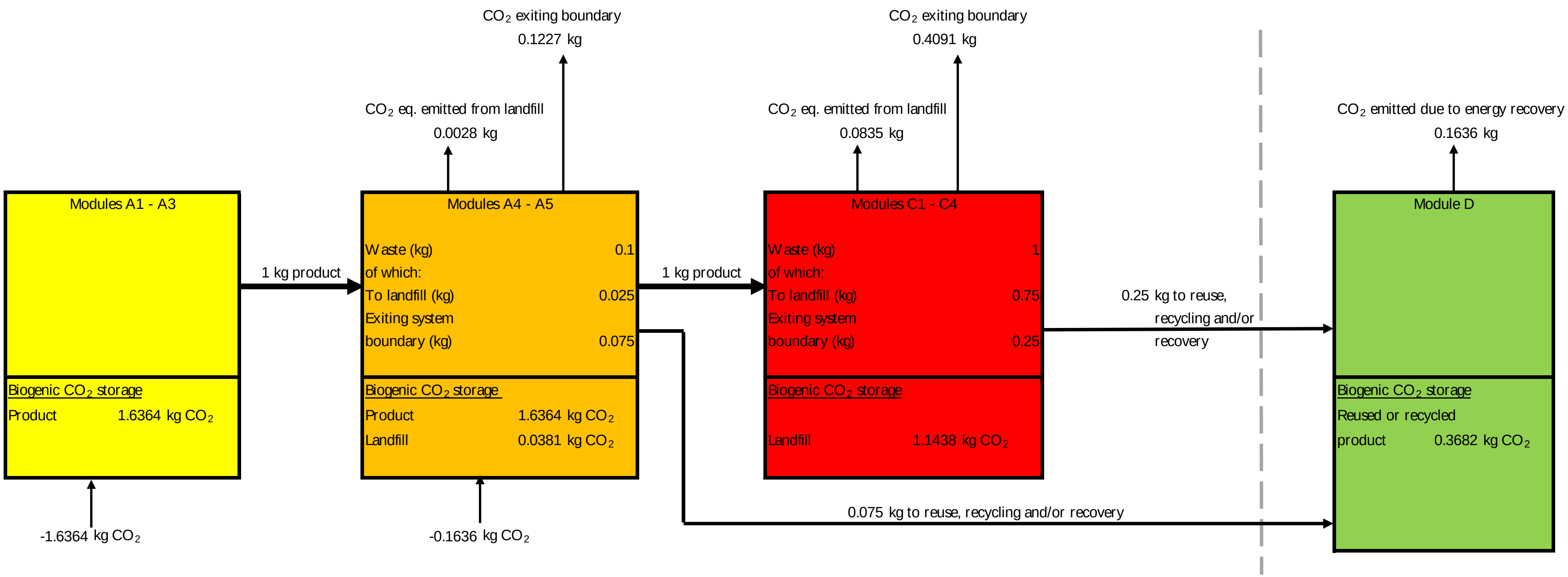
- Be in waste produced at the construction site, which goes to landfill where some decomposition occurs, leading to emissions of carbon dioxide and methane. Other sequestered carbon dioxide will remain stored in the landfill (over a 100 year timeframe).
- Be in waste produced at the construction site, which is reused, recycled or recovered, and therefore exits the system boundary as product that goes to one of these applications.
- Be in waste produced as a result of building deconstruction / demolition, which goes to landfill where some decomposition occurs, leading to emissions of carbon dioxide and methane. Other sequestered carbon dioxide will remain stored in the landfill (over a 100 year timeframe).
- Be in waste produced as a result of building deconstruction / demolition, which is reused, recycled or recovered, and therefore exits the system boundary as product that goes to one of these applications.

Waste that is reused or recycled keeps the sequestered carbon dioxide stored for the estimated service life in its application outside the system boundary. Waste that is combusted for energy recovery emits the sequestered carbon dioxide back to atmosphere. Both of these are reflected in module D.

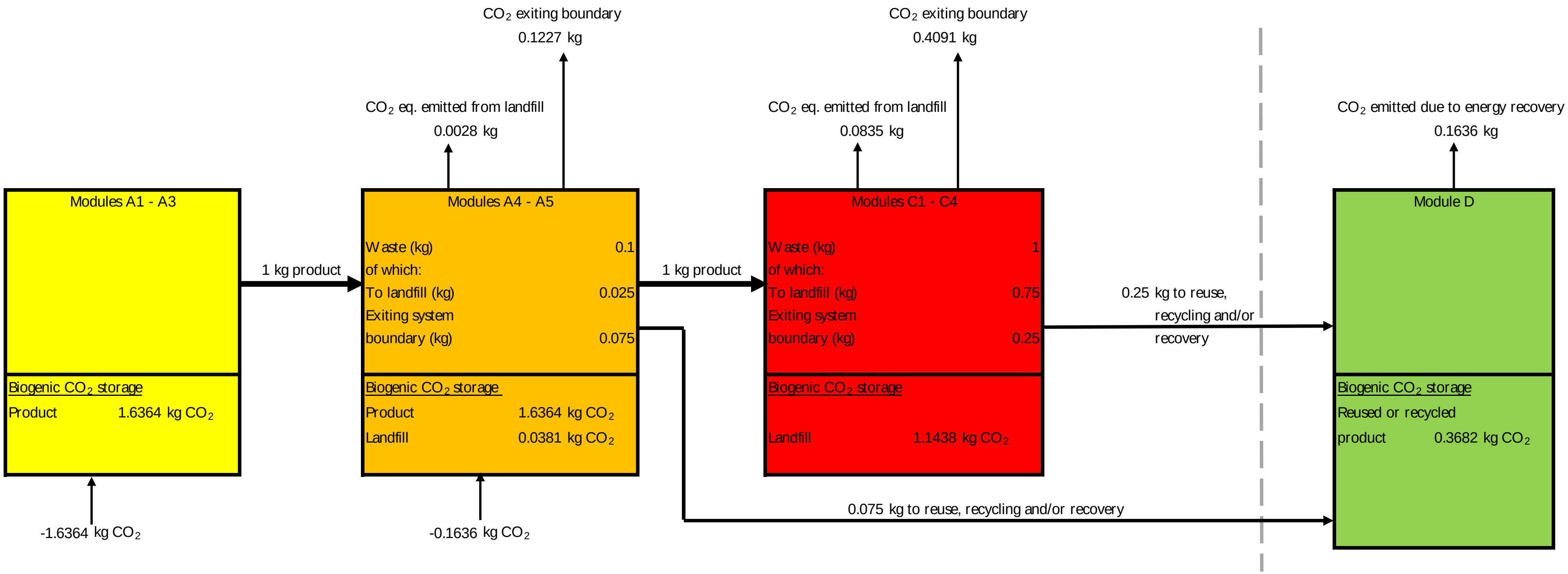
Diagrams below are divided into structural and non-structural applications. These diagrams are followed by tables summarising flows of sequestered carbon dioxide.

C2.1 Structural applications

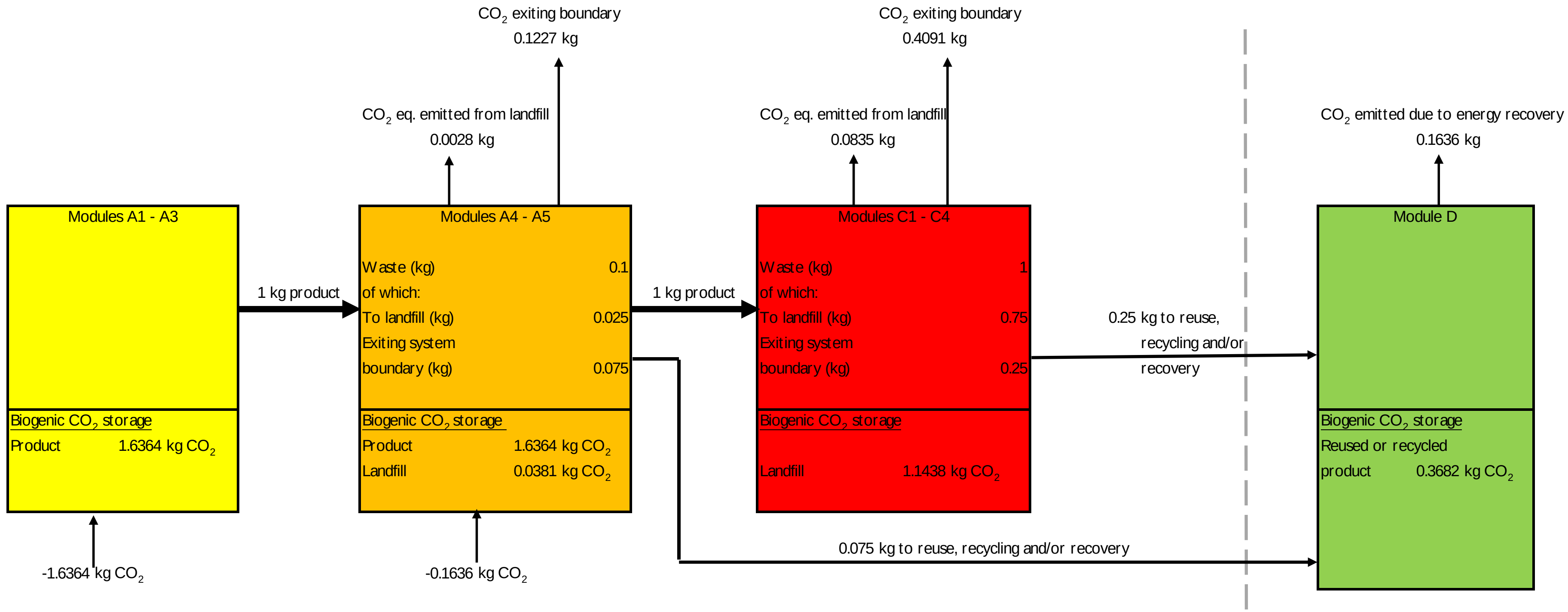
Timber, soft wood, dressed kiln-dried sections [from sustainable forest management practices]



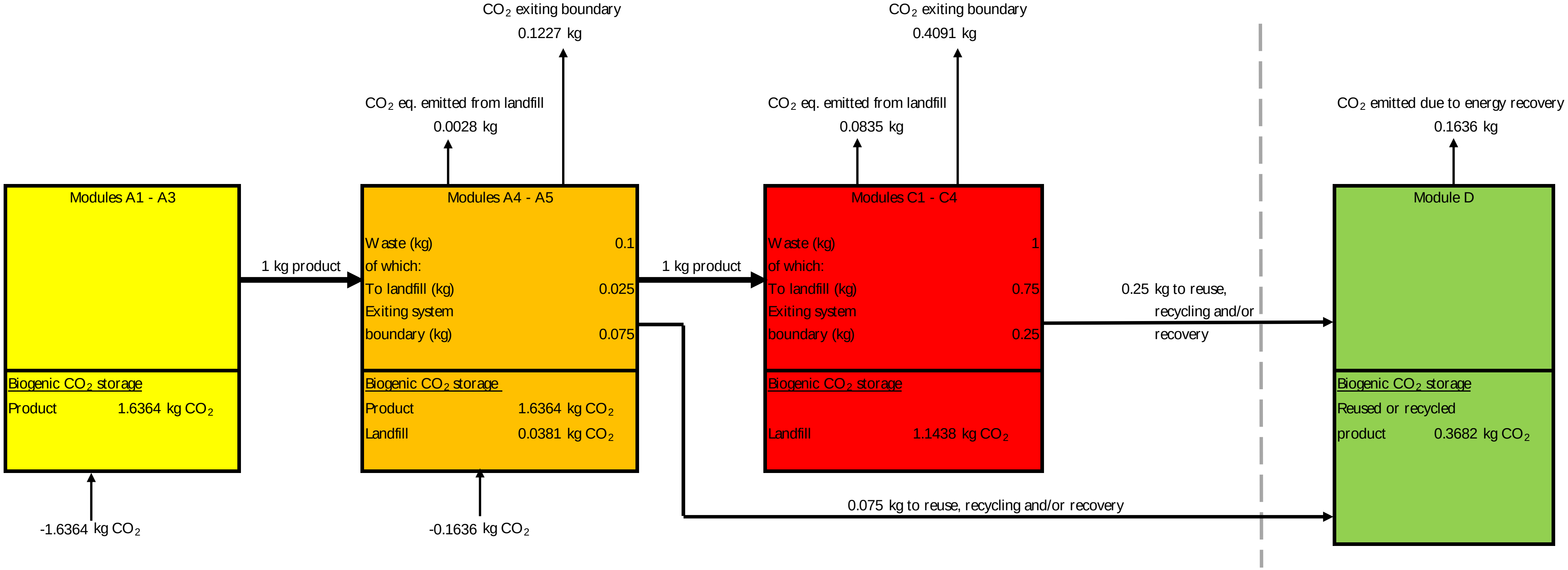
Timber wall framing, soft wood, dressed kiln-dried sections [from sustainable forest management practices]



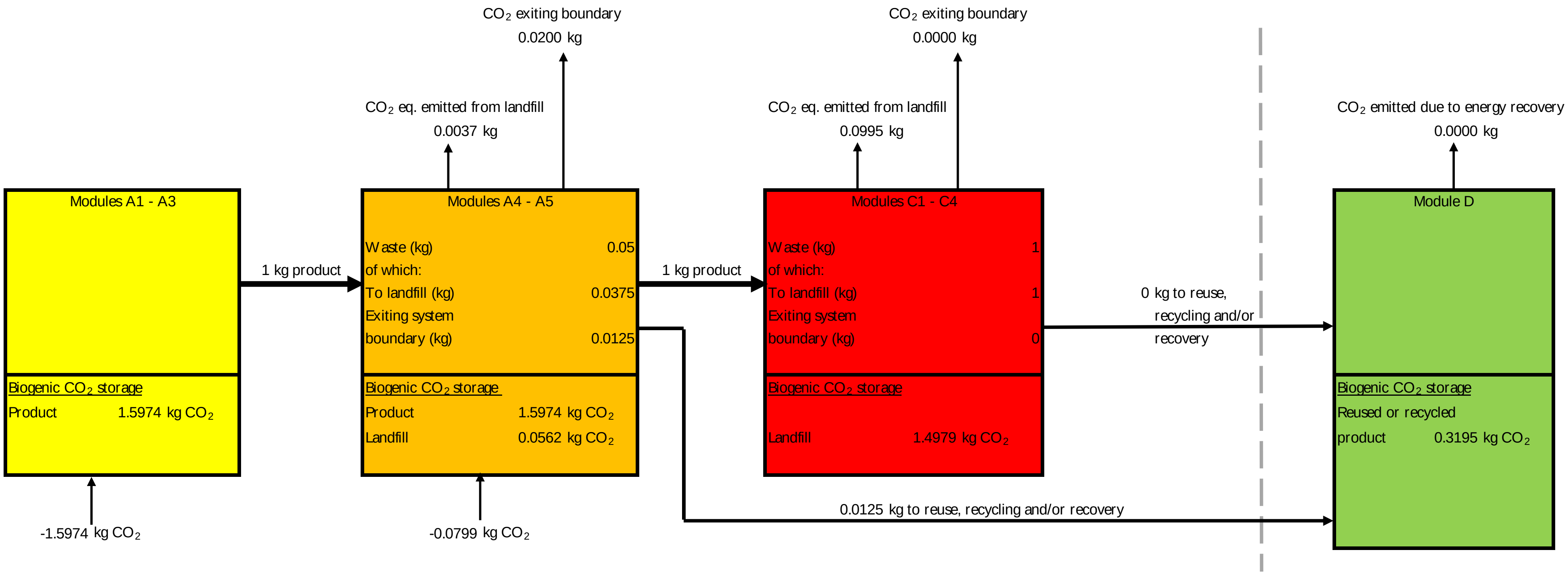
Timber structural framing, soft wood, dressed kiln-dried, interior use [from sustainable forest management practices]



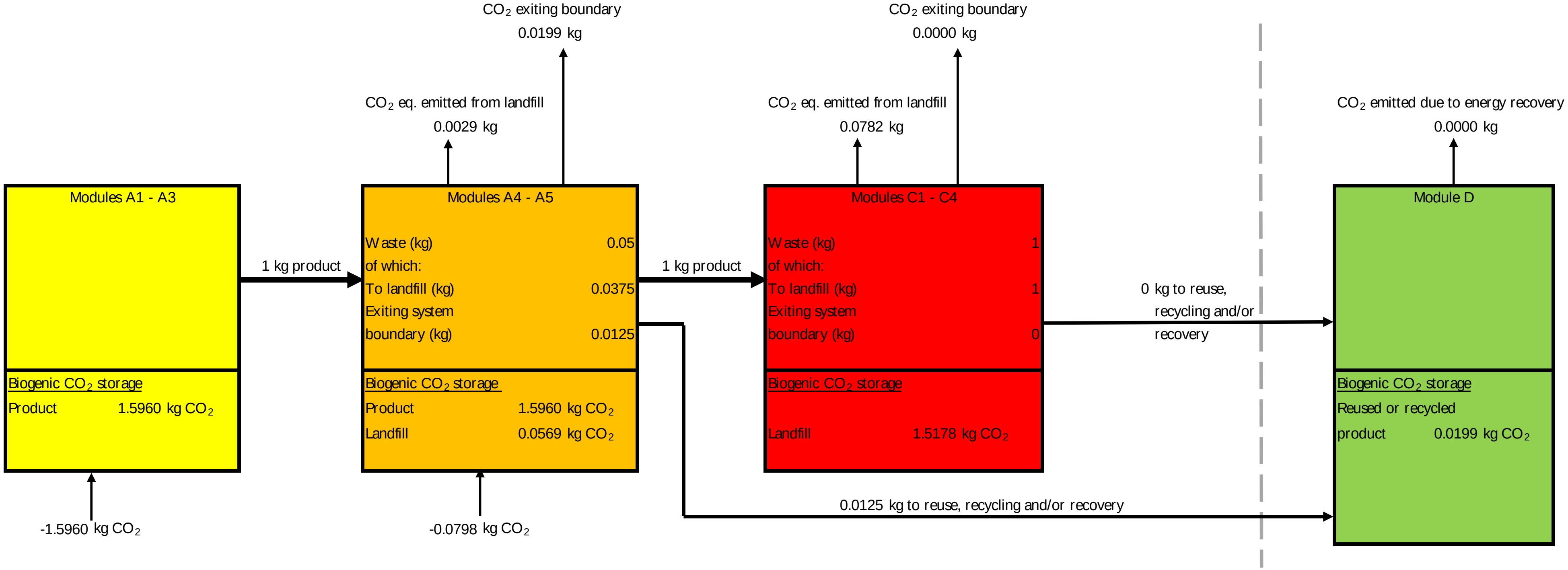
Timber structural framing, soft wood, dressed kiln-dried, exterior use [from sustainable forest management practices]



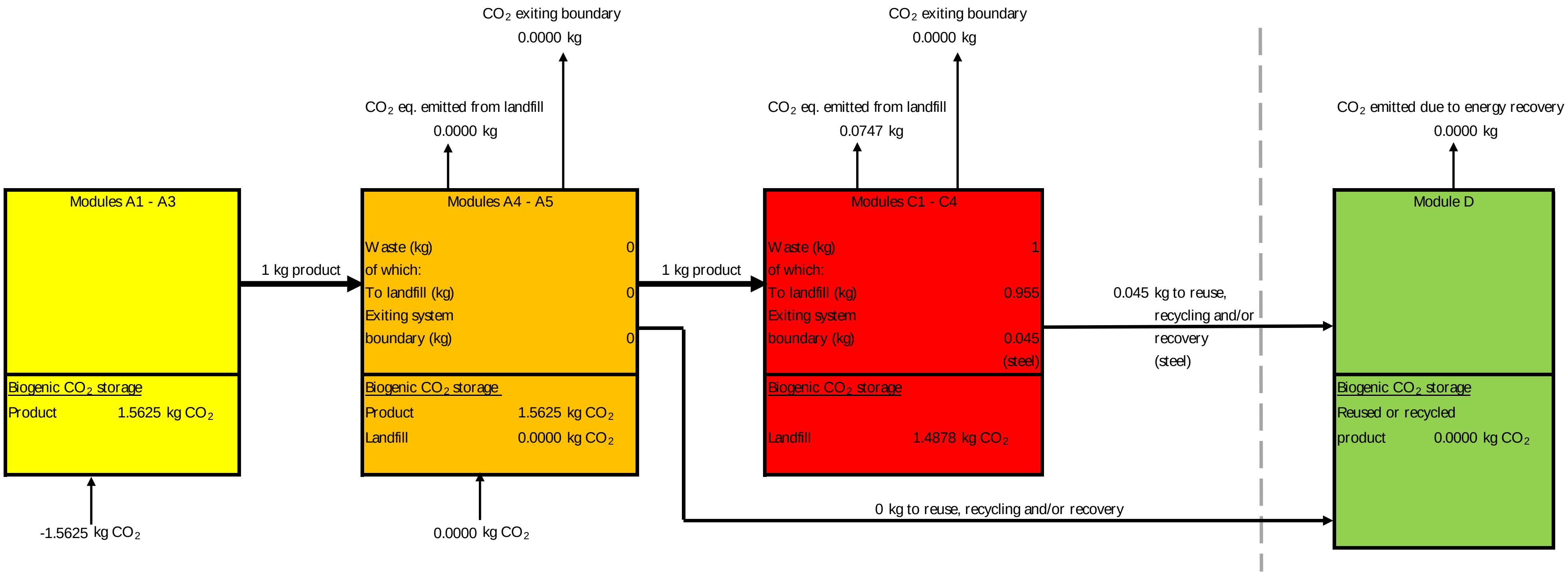
Engineered wood, glued laminated timber (Glulam, softwood) [from sustainable forest management practices]



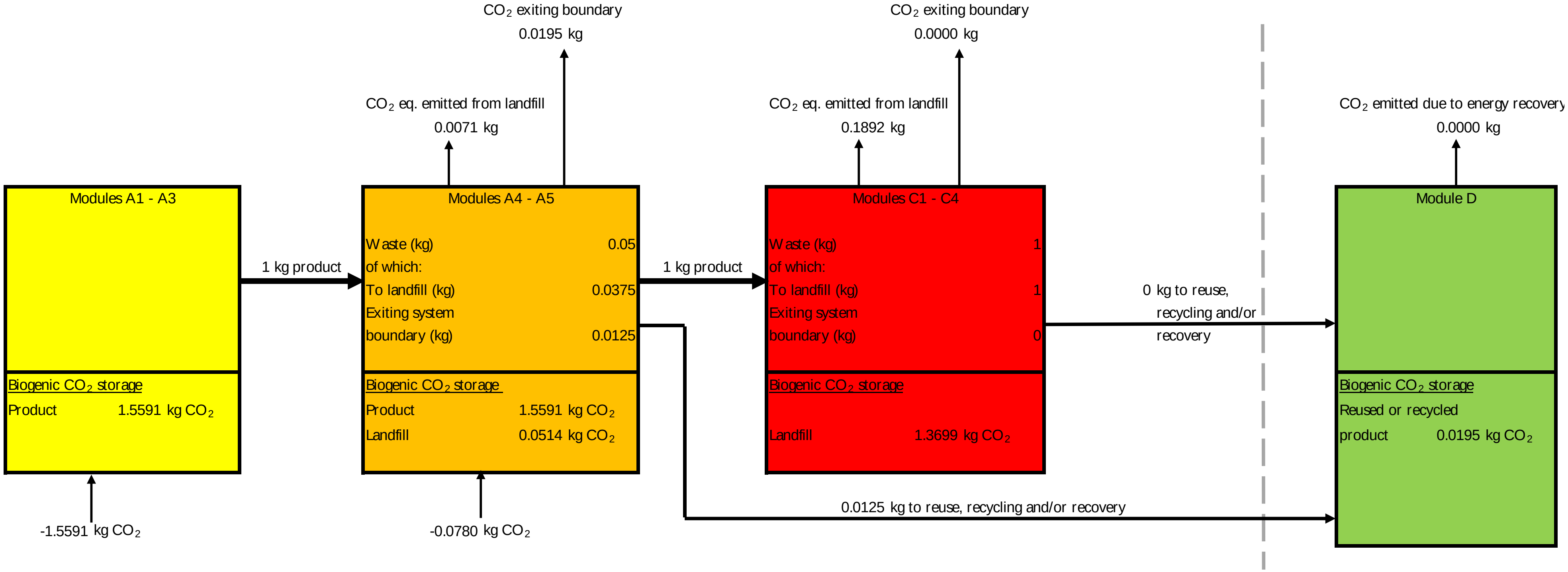
Engineered wood, laminated veneer lumber (LVL) [from sustainable forest management practices]



Post tensioned timber frame structure, laminated veneer lumber (LVL) [from sustainable forest management practices], inc. steel reinforcing

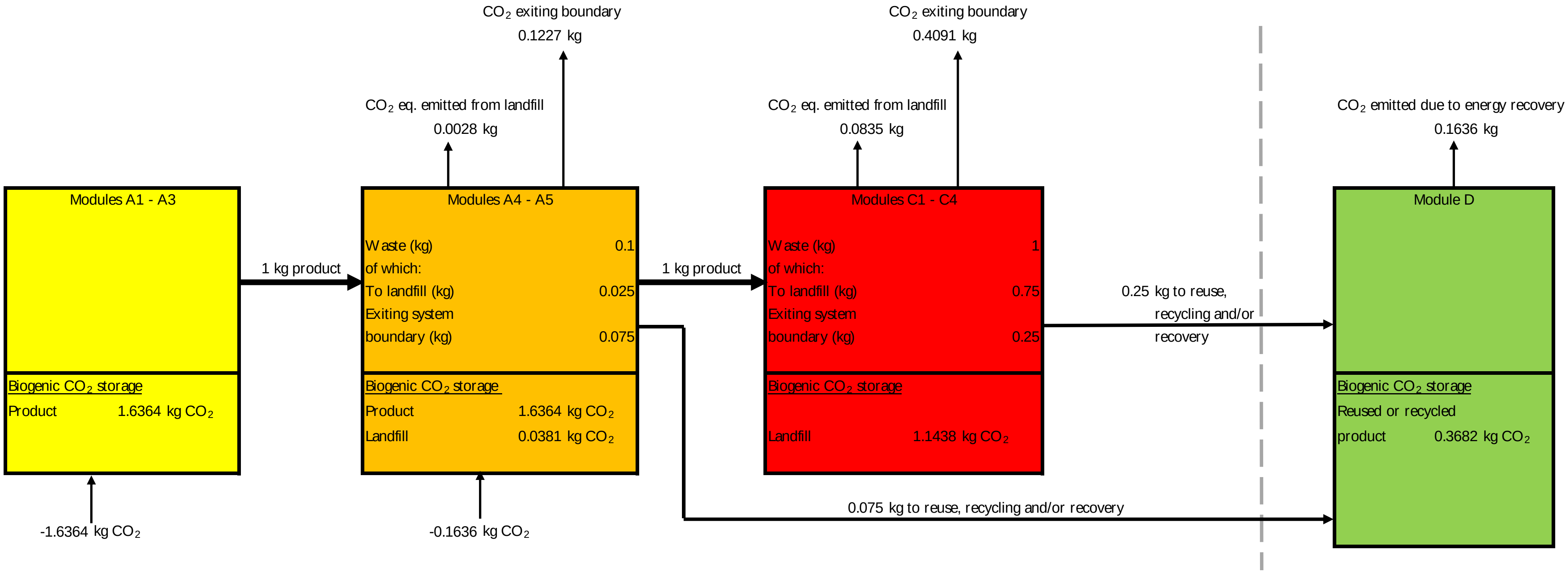


Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices]

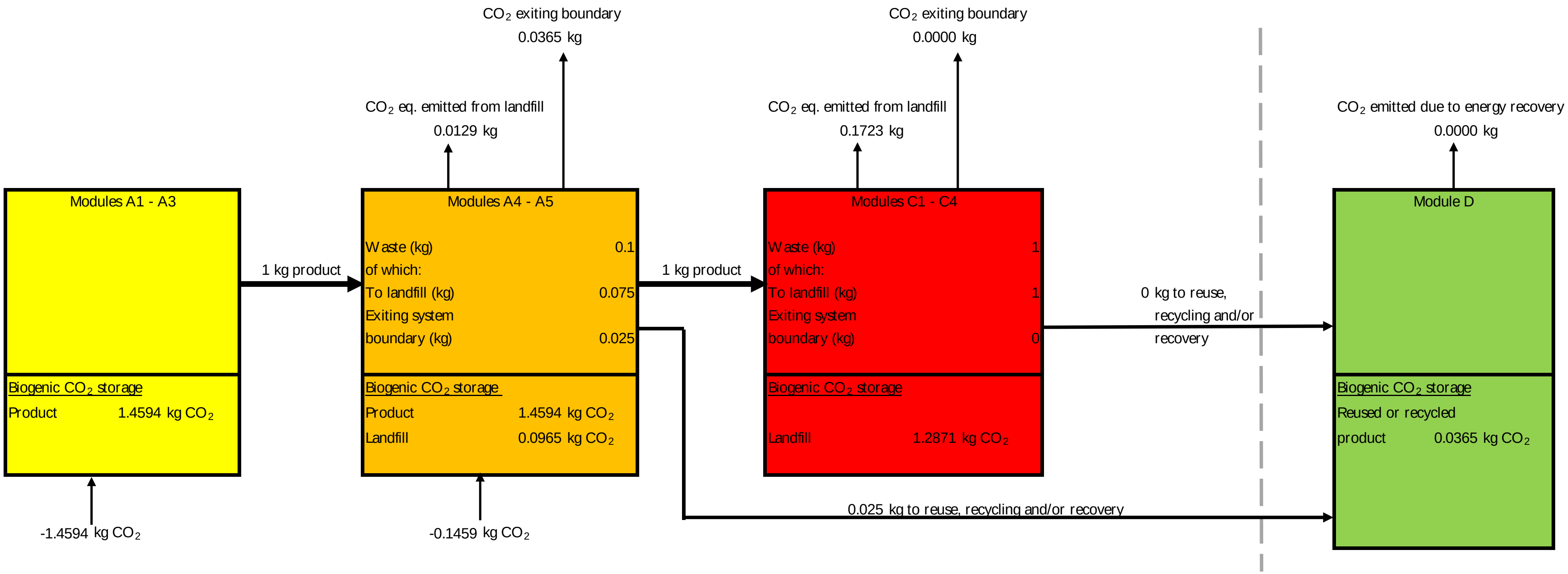


C2.2 Non-structural applications

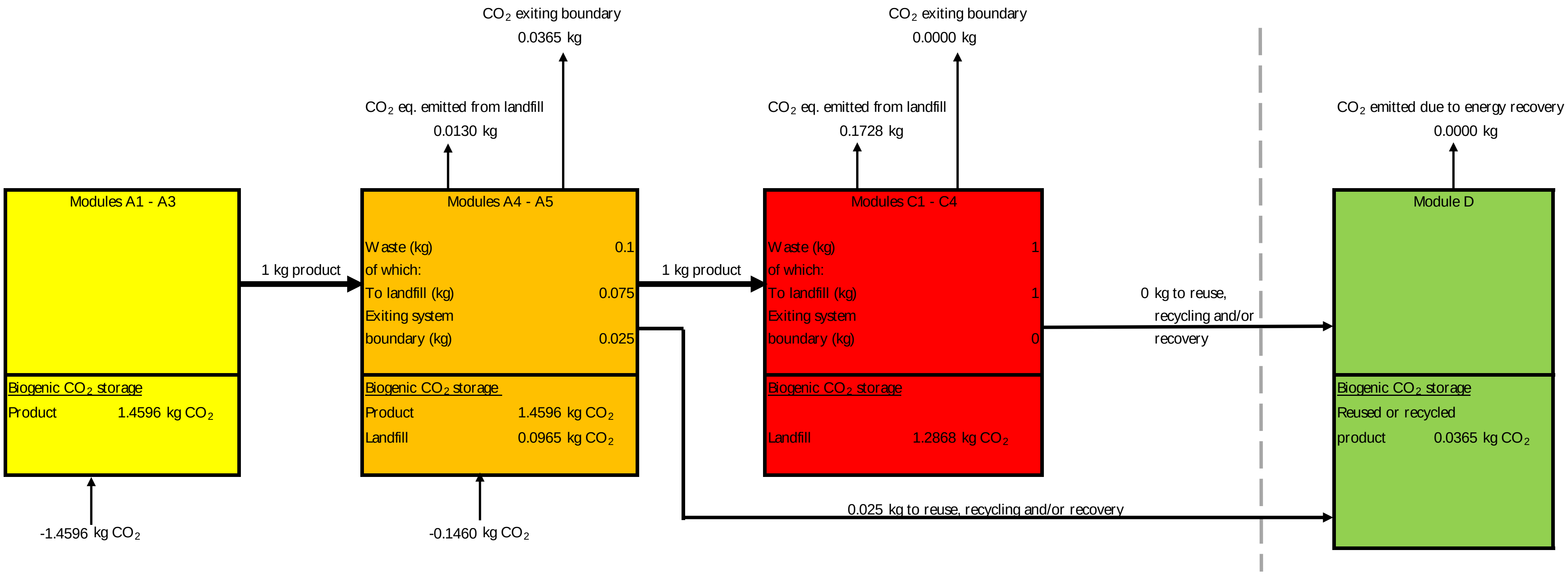
Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from sustainable forest management practices]



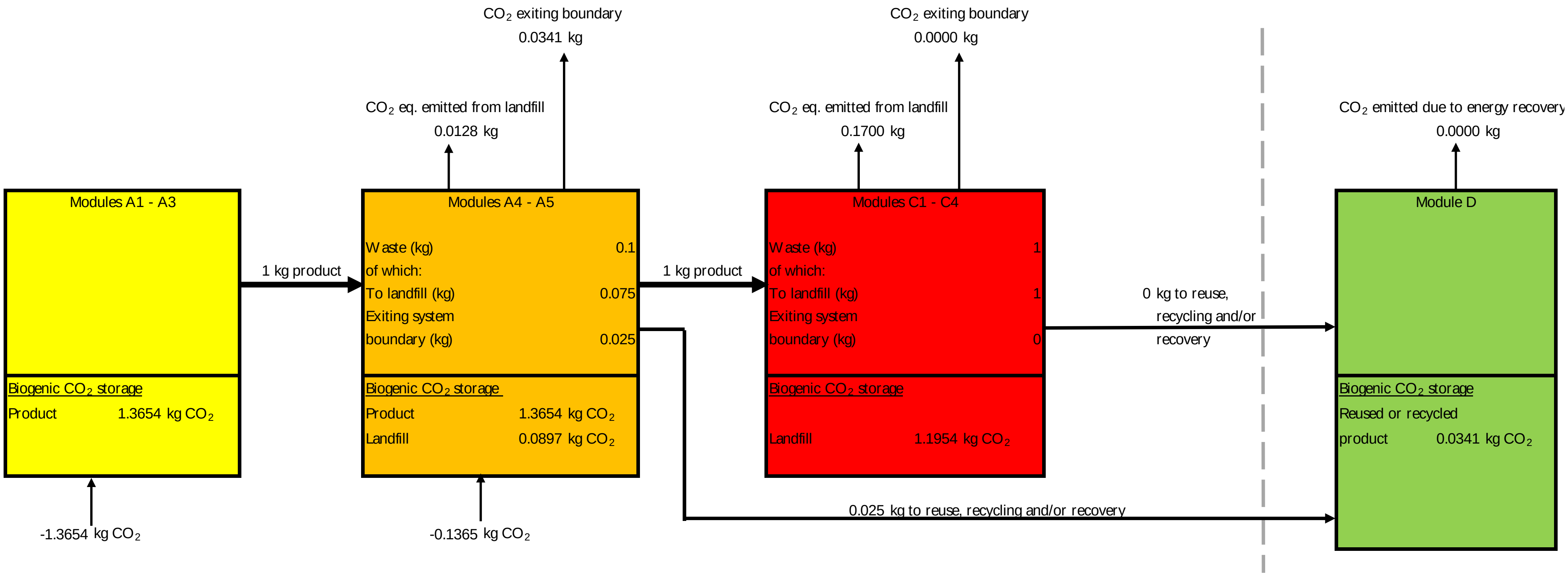
Engineered wood, plywood (exterior, A-bond) [from sustainable forest management practices]



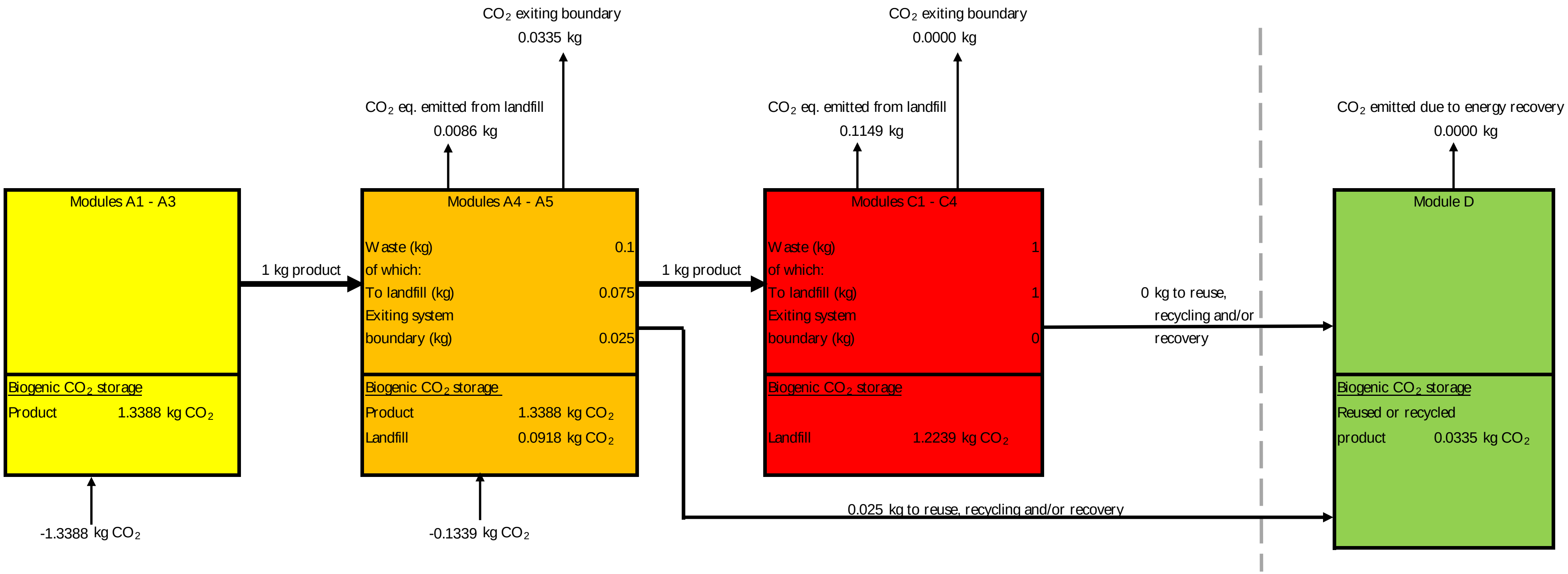
Plywood (A bond, floor) [from sustainable forest management practices], with galvanised fixings



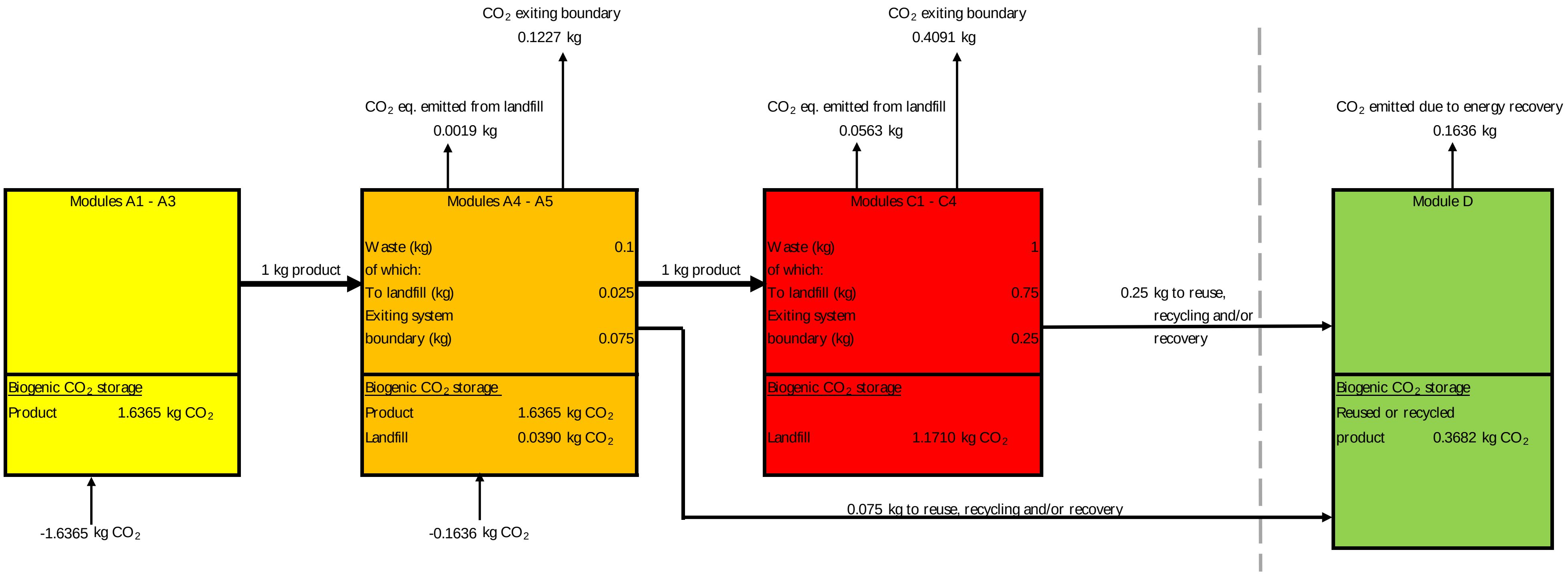
Particleboard (floor) [from sustainable forest management practices], with galvanised fixings



MDF floor [from sustainable forest management practices], with galvanised fixings (generic)



Hardwood (dressed, kiln dried) floor [from sustainable forest management practices], with galvanised fixings



Softwood (dressed, kiln dried) floor [from sustainable forest management practices], with galvanised fixings

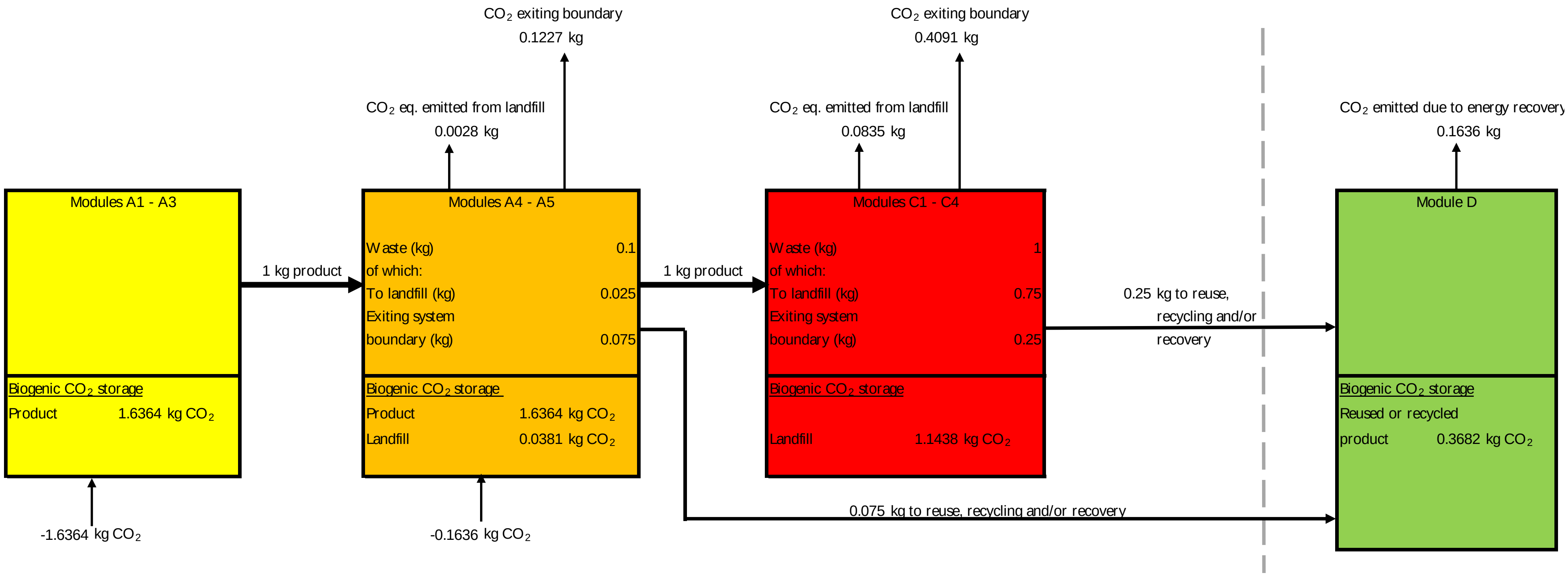


Table 15. Structural applications – summary of sequestered carbon dioxide emissions, removals and storage.

Timber and engineered wood structural applications	Total sequestered ($kg\ CO_2e$ / kg)	Total emitted from landfill ($kg\ CO_2e$ / kg)	Total stored in landfill ($kg\ CO_2e$ / kg)	Total leaving system boundary ($kg\ CO_2e$ / kg)	Total stored or out ($kg\ CO_2e$ / kg)	Emitted	Stored in landfill	Exiting system boundary
Timber, soft wood, dressed kiln-dried sections [from sustainable forest management practices]	-1.800	0.086	1.182	0.532	1.800	4.8%	65.7%	29.5%
Timber wall framing, soft wood, dressed kiln-dried sections [from sustainable forest management practices]	-1.800	0.086	1.182	0.532	1.800	4.8%	65.7%	29.5%
Timber structural framing, soft wood, dressed kiln-dried, interior use [from sustainable forest management practices]	-1.800	0.086	1.182	0.532	1.800	4.8%	65.7%	29.5%
Timber structural framing, soft wood, dressed kiln-dried, exterior use [from sustainable forest management practices]	-1.800	0.086	1.182	0.532	1.800	4.8%	65.7%	29.5%
Engineered wood, glued laminated timber (Glulam, softwood) [from sustainable forest management practices]	-1.677	0.103	1.554	0.020	1.677	6.2%	92.7%	1.2%
Engineered wood, cross laminated timber (CLT) [from sustainable forest management practices]	-1.684	0.081	1.583	0.020	1.684	4.8%	94.0%	1.2%
Engineered wood, laminated veneer lumber (LVL) [from sustainable forest management practices]	-1.676	0.081	1.575	0.020	1.676	4.8%	94.0%	1.2%
Post tensioned timber frame structure, laminated veneer lumber (LVL) [from sustainable forest management practices], inc. steel reinforcing	-1.562	0.075	1.488	0	1.562	4.8%	95.2%	0%
Engineered wood, I-joist profile, 200x45 [from sustainable forest management practices]	-1.637	0.196	1.421	0.019	1.637	12.0%	86.8%	1.2%

Table 16. Non-structural applications – summary of sequestered carbon dioxide emissions, removals and storage.

Timber and engineered wood non-structural applications	Total sequestered ($kg\ CO_2e$ / kg)	Total emitted from landfill ($kg\ CO_2e$ / kg)	Total stored in landfill ($kg\ CO_2e$ / kg)	Total leaving system boundary ($kg\ CO_2e$ / kg)	Total stored or out ($kg\ CO_2e$ / kg)	Emitted	Stored in landfill	Exiting system boundary
Timber weatherboards, soft wood, dressed kiln-dried, all profiles [from sustainable forest management practices]	-1.800	0.086	1.182	0.532	1.800	4.8%	65.7%	29.5%
Engineered wood, plywood (exterior, A-bond) [from sustainable forest management practices]	-1.605	0.185	1.384	0.036	1.605	11.5%	86.2%	2.3%
Plywood (A bond, floor) [from sustainable forest management practices], with galvanised fixings	-1.606	0.186	1.383	0.036	1.606	11.6%	86.2%	2.3%
Particleboard (floor) [from sustainable forest management practices], with galvanised fixings	-1.502	0.183	1.285	0.034	1.502	12.2%	85.6%	2.3%
MDF floor [from sustainable forest management practices], with galvanised fixings (generic)	-1.473	0.124	1.316	0.033	1.473	8.4%	89.3%	2.3%
Hardwood (dressed, kiln dried) floor [from sustainable forest management practices], with galvanised fixings	-1.800	0.058	1.210	0.532	1.800	3.2%	67.2%	29.5%
Softwood (dressed, kiln dried) floor [from sustainable forest management practices], with galvanised fixings	-1.800	0.086	1.182	0.532	1.800	4.8%	65.7%	29.5%