JCH INDUSTRIAL ECOLOGY LIMITED

EPD REVIEW SOLID AND MODIFIED WOOD PRODUCTS FOR WINDOW AND DOOR JOINERY APPLICATIONS

August 29, 2023

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FINAL

Client:
Abodo Wood Ltd., 62 Ascot Road, Mangere, Auckland 2022, New Zealand (www.abodo.co.nz)

Circulation: At discretion of Abodo Wood

Whilst every effort has been made to ensure the accuracy of the data in this report, if any errors are noted please notify the author (enquiries@jchindustrial.co.uk)

Executive Summary

JCH Industrial Ecology Ltd was engaged by Abodo Wood Ltd to conduct a survey of published EPDs of unmodified, chemically modified and thermally modified wood products, typically used for window and door joinery comparing global warming potential (GWP), sequestered atmospheric carbon, embodied energy and inherent energy (calorific content). A total of 6 timber product EPDs have been compared, for chemically-modified and thermally-modified radiata pine. Only life cycle stages A1-A3 (forest to factory gate) have been analysed.

It was also requested that EPD data be examined for Sapele and Red Grandis as these are commonly used window and door timbers, but no EPDs exist. However, a general search for carbon footprint data on tropical hardwoods was conducted and the results of this search are included in the report. The data obtained is not comparable with the EPD data since a different LCA methodology has been followed.

Comparison of EPDs

Embodied energy and GWP

The GWP and embodied energy data for the published timber EPDs are shown in Appendices 1 and 2, respectively. The following EPDs were analysed:

EPD reg. no.	Product
S-P-00997	Sawn dried radiata (WPMA)
S-P-00997	Sawn dried and planed radiata (WPMA)
S-P-01543	TMT Vulcan radiata sawn (Abodo)
S-P-01543	TMT Vulcan radiata sawn and planed (Abodo)
S-P-01718	TMT Brimstone Ash sawn
S-P-01718	TMT Brimstone Sycamore sawn
NEPD-376-262-EN	Accoya (radiata) (Accys)
Agrodome	Accoya (radiata) (Accys)
EPDIE-22-107	Tricoya (Accys)

The declared unit for the EPDs is one cubic metre of timber product.

Unmodified radiata pine

S-P-00997 is for unmodified radiata pine and has been included as a baseline.

The EPD is published by the International EPD System (EPD Australasia) and was published 01/10/2019 and follows the EN 15804+A1 PCR.

The owner of the EPD is the Wood processors and Manufacturers Association of New Zealand. The EPD declares the environmental impacts associated with the production of sawn kiln-dried, surfaced kiln-dried, finger-jointed, glulam and cross-laminated timber. Only sawn and kiln-dried is discussed here. The GWP data is reproduced (units $kgCO_2e$) for modules A1-A3. The density of the products is 488 kg/m^3 at a moisture content of 11.6%. Calculating the sequestered carbon content for these two densities according to EN 16449 gives the following results (assuming a default carbon content of 50% by mass).

Density Kg/m^3	Moisture content (%)	Seq. C kgC	Seq. C $kgCO_2e$
486	11.6	-798	-218
488	11.6	-802	-219

The declared GWP values in the EPD are:

	Sawn kiln-dried	Surfaced kiln-dried
GWP-total	-747.0	-728.0
GWP-fossil	51.3	66.9
GWP-biogenic	-798.0	-795.0

The resource use is reported in units of MJ for the following categories (see later section for explanation of the abbreviations).

	Sawn kiln-dried	Surfaced kiln-dried
PERE	4200	5330
PERM	8260	8240
PENRE	552	720

A large proportion of the embodied energy associated with the product (PERE+PENRE) is declared as coming from renewable resources. Use of electricity for production has been modelled using the New Zealand grid mix for the relevant time period. The installed capacity for 2021 was 55.8% hydro, 12.6% gas, 10.6% geothermal, 9.4% wind, 5.1% coal/gas, with minor contributions from other sources.

The PERM (renewable primary energy of the material) is the calorific value of the wood. According to the EN 15804 method, the calorific value of the material is reported as the lower heating value (LHV). The calorific value of pine is 19-21 MJ/kg (www.phyllis.nl) which gives a PERM of 9272-10248 MJ (for the dry product). The quoted value is an underestimate.

Thermally modified radiata pine

Thermal modification of wood involves the application of heat to the wood in a vacuum, or under a nitrogen or steam blanket. The process involves the degradation of the hemicelluloses and increases the relative carbon content of the wood as well as reducing the hydroxyl content. The wood is more durable that unmodified and has a lower moisture content at the same relative humidity. The dimensional stability is improved. The density of the wood is reduced compared with the unmodified equivalent. The magnitude of these changes in the wood depends on the type, time and temperature of treatment.

S-P-01543 is the EPD published by the International EPD System (EPD Australasia) for Abodo thermally modified radiata pine products, dated 12/08/2020. The sawn and surfaced products are discussed here. The EPD is produced according to the EN 15804+A1 PCR. Module A4 includes transport of the material 21,000 km to Europe. According to data in the UK Government GHG Conversion Factors for Company Reporting (2021), the average GHG emissions for container vessels is 0.00363 $kgCO_2e$ per t.km. For a product of density 420 kg/m^3 travelling 21,000 km, this would produce a GWP impact of 32 $kgCO_2e$ per m^3 (this does not include road or rail transport).

The declared density of the product is 420 kg/m^3 at a moisture content of 7%, this corresponds to a sequestered carbon content of -196 kgC (-720 $kgCO_2e$), assuming a carbon content of 50%, according to EN 16449.

The declared GWP values are:

	Sawn	Surfaced	Module A4
GWP-total	-535	-516	73.4
GWP-fossil	224	243	73.3
GWP-biogenic	-758	-758	0.1

The resource use (in units of MJ) is reported for the following categories:

	Sawn	Surfaced	Module A4
PERE	4200	4740	2.5
PERM	7560	7560	0
PENRE	2970	3230	914

Thermal modification will increase the calorific value of the material, since the oxygen content of thermally modified wood is lower than unmodified wood. However, there is no information on thermally modified wood in the Phyllis database. If we use 21 MJ/kg as the calorific value of the material, the PERM is 8243 MJ (for the dry product) and if 19MJ/kg is used the PERM is 7458 MJ (dry).

S-P-01718 International EPD System for Brimstone Ash TMT dated 09/10/2019. It is produced according to the EN 15804+A1 PCR.

The declared density is 631 kg/m^3 at a moisture content of 4-6%. The wood is supplied as a profiled product.

The sequestered carbon is taken into account and calculated according to EN 16485 with the declared sequestered carbon being -1110 kg/m^3. Using the declared density and a MC of 4% gives -1112 kg/m^3, assuming that the carbon content is 50% by weight (it will be slightly higher than this in modified wood).

The GWP-total is declared as -704 kg/m^3. Subtracting the reported sequestered carbon value from this gives +406 kgCO_2e, which is the GHG emissions associated with the production of 1m^3 of TMT Ash.

Apart from reporting the total emissions and removals of GHGs as the sum of modules A1-A3, the EPD also reports these separately for each module.

	A1	A2	A3	TOTAL (A1-A3)
GWP-total	-2223	93	1427	-704

Check: 93+1427-2223 = -703

The A3 entry is divided into the following categories:

Operation	GWP (kgCO_2e/m^3)
Milling and kilning	1240
Preparation for thermal mod	3
Thermal modification	177
Profiling	7
TOTAL	**1427**

The resource use is reported in units of MJ for the following categories:

PERE	22200
PERM	9250
PENRE	6480

S-P-01718 International EPD System for Brimstone Sycamore TMT dated 09/10/2019. It is produced according to the EN15804+A1 PCR.

The declared density is 571 kg/m^3 at a moisture content of 4-6%. The wood is supplied as a profiled product.

The sequestered carbon is taken into account and calculated according to EN 16485 with the declared sequestered carbon being -1010 kg/m^3. Using the declared density and a MC of 4% gives -1006 kg/m^3, assuming that the carbon content is 50% by weight (it will be slightly higher than this in modified wood) using the methodology described in EN 16449.

The GWP-total is declared as -639 kg/m^3. Subtracting the reported sequestered carbon value from this gives +371 kgCO_2e, which is the GHG emissions associated with the production of 1m^3 of TMT sycamore.

Apart from reporting the total emissions and removals of GHGs as the sum of modules A1-A3, the EPD also reports these separately for each module.

	A1	A2	A3	TOTAL (A1-A3)
GWP-total	-2005	90	1395	-639

Check: 90+1395-2005 = -520

The total according to the values reported for modules A1-A3 is -520 kgCO_2e, rather than the reported -639 kgCO_2e. It is uncertain which value is correct. However, Fig. 2 of the EPD shows in a bar chart that the values associated with milling and kilning are different for ash and sycamore, but the same numbers are attached (i.e., 1240 kgCO_2e) suggesting a typographical error in the case of sycamore.

The A3 entry is divided into the following categories:

Operation	GWP (kgCO_2e/m^3)
Milling and kilning	1240
Preparation for thermal mod	3
Thermal modification	146
Profiling	6
TOTAL	**1395**

The resource use is reported in units of MJ for the following categories:

PERE	18100
PERM	10400
PENRE	5810

Chemically-modified radiata pine

NEPD-376-262-EN was published by the Norwegian EPD Foundation (EPD Norge) on 18/12/2015, but is included because the current EPD owned by Accys Technologies for the Accoya product is not registered with an EPD Program Operator. The product is sold as planed timber.

The quoted density for the product is 510 kg/m^3, with a moisture content 3-5%. If EN 16449 is used to calculate the sequestered carbon content from these data, this gives a value of -899 kgCO_2e (4% MC) and -935 kgCO_2e (0% MC).

The carbon sequestration is stated to be -1.85 kg CO_2 per kg Accoya, corresponding to -944 kg CO_2 per m^3 of radiata pine.

The GWP-total is quoted at -433 kgCO_2e, subtracting the sequestered carbon from this value yields a GWP-GHG value of 511 kgCO_2e, which are the GWP emissions associated with entire process for modules A1-A3.

As was noted in the previous report, the calculation of the sequestered carbon in the Accoya was based on the product density, which also includes the weight gain due to acetylation. However, the acetic anhydride used for the acetylation product does not contain biogenic carbon. This does not invalidate the above method used to infer the GWP emissions.

Since the sequestered atmospheric carbon in the Accoya is only associated with the radiata pine, the sequestered carbon in the product will be that quoted for 1 m^3 of unmodified radiata pine (actually, slightly lower, since the radiata pine swells when modified). The value quoted for unmodified radiata pine in EPD S-P-00997 is slightly less than -800 kgCO_2e/m^3.

The energy values reported in the resource use category are:

PERE	847
PERM	6574
PENRE	14559
PENRE	2549

The main contribution to the embodied energy is from non-renewable resources. The non-renewable primary energy in the material is included in the table because the bonded acetyl groups contribute to the calorific value of the material. The renewable primary energy associated with the material (PERM) is the calorific value of the wood and would be expected to be comparable with the value quoted in EPD S-P-00997, but is much lower.

The EPD also includes an alternative model where the acetic acid generated during the acetylation process is used to substitute for manufactured acetic acid derived from a fossil feedstock. The quoted GWP under this scenario is -709 kgCO_2e. This is not discussed further.

Agrodome EPD this EPD is not registered with an EPD operator, although it is based upon the EN 15804+A2 PCR and has been independently verified. Only modules A1-A3 are reported, which is not in accordance with the Product Category Rules in EN 15804+A2, which states that:

'*cradle to gate (A1–A3). These stages are the minimum to be declared for all construction products that are exempt from declaring modules C and D and shall be based on a declared unit. This type of EPD is not allowed for products containing biogenic carbon*'

The quoted density of the product is 515 kg/m^3, with a moisture content of 3-5%.

The biogenic carbon stored in the material is reported to be -802.4 CO_2e, which is a reasonable value. Since the biogenic carbon is declared, the EPD should also declare modules C and D. This EPD is intended for use by Accoya customers who would use the data for their won EPDs.

The quoted GWP values (kgCO_2e) for modules A1-A3 is:

	A1	A2	A3	TOTAL (A1-A3)
GWP-total	-131	61.4	197	127.4
GWP-fossil	555	61.2	194	810.2
GWP-biogenic	-687	0.1	3.2	-683.7
GWP-luluc	0.4	0.05	0.06	0.51

The -687 kgCO_2e reported in module A1 includes the uptake of -802.4 kgCO_2e in the wood and it is stated that this shall be released when the product reaches the end-of-life stage. The difference between the two values indicates that some biogenic carbon has left the system (either incinerated, or exported as waste to another process). From the above data, it is assumed that the GWP emissions associated with the production of 1 m^3 of Accoya are 810 kgCO_2e per m^3, considerably higher than reported in the previous EPD.

The resource use energy categories (MJ) are:

	A1	A2	A3	SUM A1-A3
PERE	589	14.6	198	801.6
PERM	0	0	0	0
PENRE	15600	868	3210	19678

This EPD has a zero entry for PERM which is an error.

Medite Tricoya Extreme

EPDIE-22-107 this EPD is registered with EPD Ireland and dated 12/12/2022. It has been produced to the latest (+A2) version of EN 15804.

The density of the product is 720 kg/m^3.

The quoted GWP values (kgCO_2e) for modules A1-A3 are:

	A1	A2	A3	TOTAL A1-A3
GWP-total	+503	+32.5	+325	+861
GWP-fossil	+1550	+32.4	+118	+1700
GWP-biogenic	-1050	-0.02	+207	-840
GWP-luluc	+1.1	+0.001	+0.13	+1.2

The sequestration of atmospheric carbon is shown in module A1 and reports the sequestered carbon in the unprocessed logs. Some biomass is exported out of the system (wet bark) and some biomass is burnt in onsite boilers (shown as emissions in A3), hence the total GWP-biogenic for modules A1-A3 is not the same as the total amount of sequestered carbon in the Tricoya product.

The total sequestered carbon in 1m^3 of Tricoya product is reported as -242.4 kgC (-888.8 kgCO_2e). The difference between this value and the reported biogenic carbon value presumably indicates that some biogenic carbon is lost as emissions or is exported from the system.

The resource use energy categories (MJ) are:

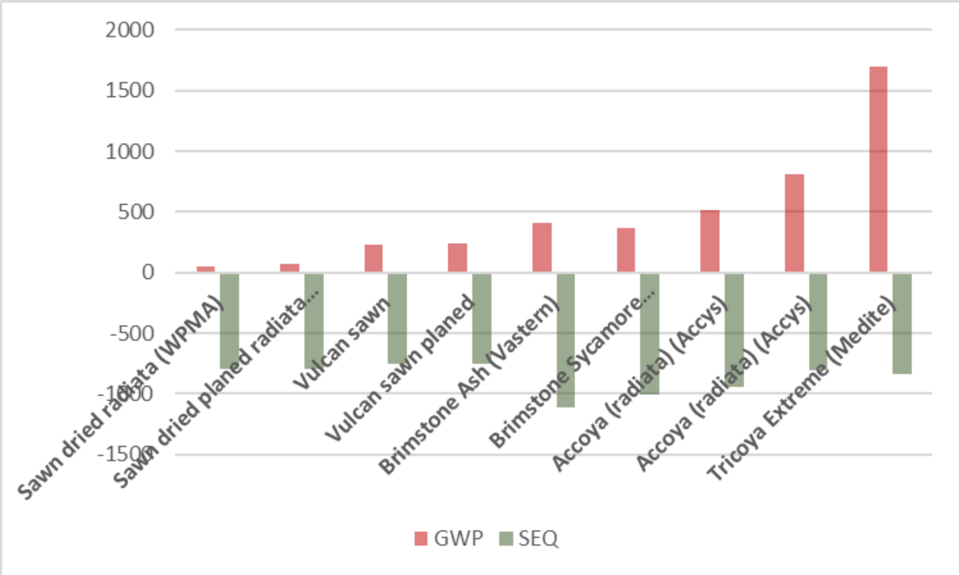
	A1	A2	A3	TOTAL A1-A3
PERE	1680	6.8	3890	5570
PERM	0	0	0	0
PENRE	36000	556	1930	38400

The primary renewable energy in the material is reported as zero in the EPD, which is incorrect.

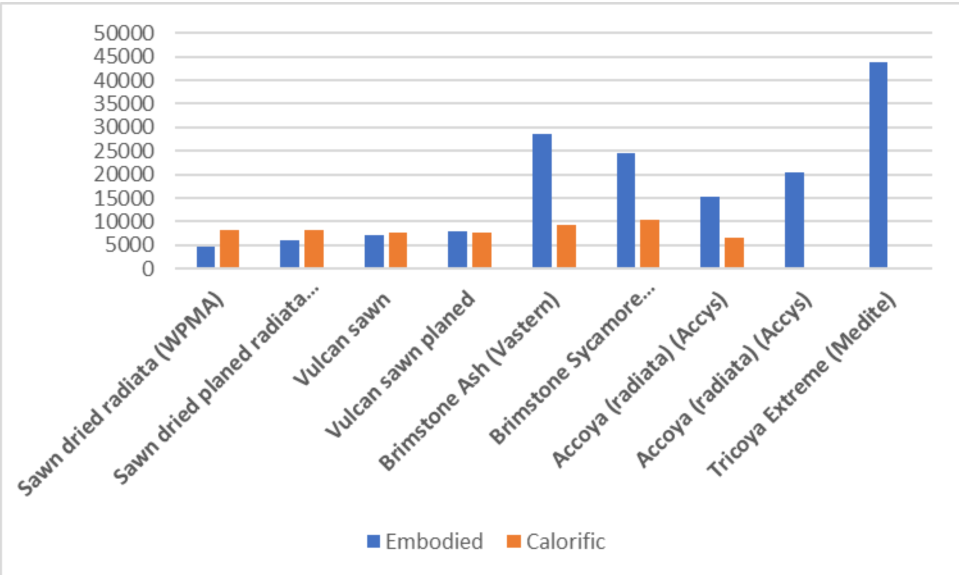
Comparison of the published EPDs

The results are reproduced in Appendix 1 and 2 and shown graphically here.

A comparison of the analysed products is shown below for GWP(kgCO_2e/m^3).

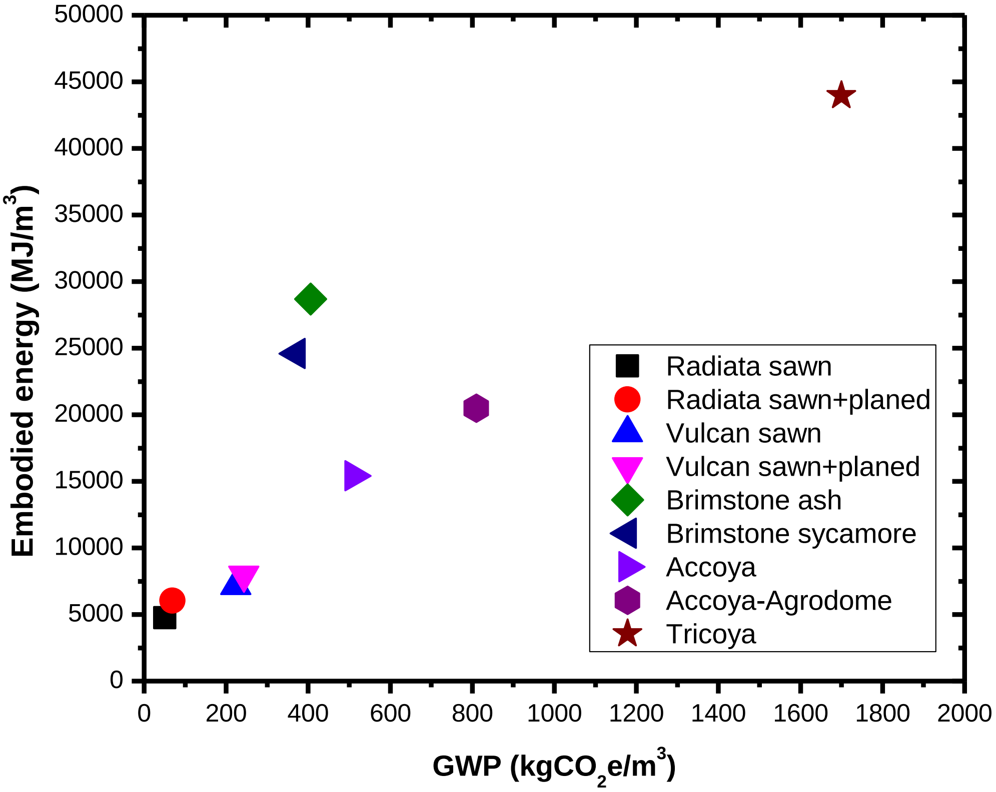


The embodied energy and calorific content of the wood products are compared below (MJ/m^3). In most cases, the stored atmospheric carbon exceeds the GHG emissions associated with the production of the material (exceptions being Accoya – Agrodome EPD and Tricoya).



The calorific content of the unmodified radiata pine and the Vulcan sawn product exceeds the embodied energy, but this is not the case for the other products analysed. This is based upon reported data and the assumption that all the calorific content is recoverable (which is not possible and varies depending upon the thermal process).

The relationship between embodied energy and GWP is shown below.



This shows a strong linear relationship between embodied energy and GWP, but that the two Vastern products have a higher embodied energy compared to GWP than would be expected from the other data. There are various reasons why this might be the case, but without access to the underlying LCA model it is not possible to explain the apparent discrepancy. This was also noted in the previous report. The relationship between embodied energy and GWP is affected by many factors, including grid energy mix, primary energy sources used for various processes, transportation, process efficiencies.

Background information

Introduction to EPDs

LCA can be a useful tool when applied to a specific product or process in order to determine where the highest environmental burdens (hotspots) occur. This attributional form of LCA can be used to identify where best to improve the process to reduce the overall environmental burden of the product. Consequential LCA can be used to determine the environmental impacts arising due to possible changes to the production process.

However, the use of LCA to compare between different materials (such as concrete or timber in construction) is much more problematic and the use of LCA for this purpose requires several criteria to be met:

- The functional unit should be the same
- The whole lifecycle of the material or product should be considered and there should be reasonable and realistic assumptions (e.g., about recycling)
- Reasonable scenarios about maintenance and replacement must be included
- The databases and environmental impact calculation methods used should be stated and be comparable
- The methodologies and inventories should be transparent (often not possible due to commercial confidentiality
- Reasonable cut-offs should be used and justified with a sensitivity analysis
- The impact categories used should be reliable and meaningful
- A sensitivity analysis should be used to demonstrate the impacts of different assumptions

In order to develop a framework that allows for comparability of environmental performance between products, ISO 14025 was introduced. This describes the procedures required to produce Type III environmental declarations. This is based on the principle of developing product category rules (PCR) which specify how the information from an LCA is to be used to produce an environmental product declaration (EPD). A PCR will typically specify what the functional unit is to be for the product. Within the framework of ISO 14025, only the production phase (cradle to gate) of the lifecycle has to be included in the EPD, but it is also possible to include other lifecycle stages, such as the in-service stage and the end-of-life stage. ISO 14025 also gives guidance on the process of managing an EPD programme. This requires programme operators to set up a scheme for the publication of a PCR under the guidance of general programme instructions. There have been other standards issued that apply to the construction sector in order to ensure greater comparability of the environmental performance of products. ISO 21930 gives some guidance on both PCR and EPD development. The European standard is EN 15804, which is a core PCR for building products and it is therefore considerably more detailed and prescriptive than ISO 14025.

The primary purpose of an EPD according to ISO 14025 is for business to business (b2b) communication, but an EPD can also be used for business to consumer (b2c) communication. In the latter case, there are further requirements upon the process, which apply especially to the verification procedures. In any case, ISO 14025 encourages those involved in the production of an EPD to take account of the level of awareness of the target audience. Standards are increasingly removing the flexibility (and uncertainty) that was once associated with determining the environmental performance of products and services. This should, in principle, make it much easier to compare the environmental impacts of products within a product category in the future.

The life cycle stages of a product can be divided into:

- Upstream processes: involving the extraction of raw materials and transport thereof to the manufacturing facilities
- Core processes: manufacture of the analysed product, maintenance of manufacturing infrastructure, packaging, disposal of waste
- Downstream processes: transportation from manufacturing to construction sites, construction, maintenance, reuse, recycling, recovery, disposal

These different life cycle phases can be further sub-divided, as shown below:

Module	Life cycle stage	Description
A1	Production	Raw material supply
A2	Production	Transport
A3	Production	Manufacturing
A4	Construction	Transport
A5	Construction	Construction/installation
B1	Use	Use
B2	Use	Maintenance
B3	Use	Repair
B4	Use	Replacement
B5	Use	Refurbishment
B6	Use	Operational energy use
B7	Use	Operational water use
C1	End of life	De-construction/demolition
C2	End of life	Transport
C3	End of life	Waste processing
C4	End of life	Disposal
D	Beyond building life cycle	Reuse/recovery/recycling

The different life cycle stages are divided into modules in EN15804, modules A1-A3 cover the production stage, A4-A5 the construction process, B1-B7 the use stage and C1-C4 the end-of-life stage; beyond this is the ‘after-life’ stage (D). The publication of this standard ensures harmonisation of core PCRs for building products in Europe with Product Environmental Footprint PCRs. It is mandatory to report stages A1-A3, with the other stages being included for any reporting beyond cradle to factory gate. If biogenic carbon is included in the product, then life cycle stages C and D must be reported in the EPD.

In theory, the introduction of EPDs which use common PCRs means that it should be possible to compare different building materials in terms of environmental impact. However, while it may be possible to make choices based upon the environmental impacts associated with the manufacture of products, the use phase and end of life phase also need to be considered in order to get the whole picture. Important considerations when examining the environmental consequences of the use of different materials must include the service life of the product, maintenance requirements and performance in service, especially with respect to the impact on the operating energy of the building. This can involve assumptions being made regarding life span, maintenance, end of life scenarios, etc., which will have a critical impact upon the outcome of the LCA. Although the introduction of Type III environmental declarations theoretically allows for environmental performance comparisons to be made between different products and materials, this may not always be possible in practice. Gelowitz and McArthur (2017) conducted a review of published EPDs for building products and came to the following conclusions:

- Discrepancies between life cycle inventory methodology, environmental indicators and life cycle inventory databases were a barrier to making comparisons between EPDs.
- There was a high level of incomparability between EPDs using the same PCR, which was unexpected and should not occur.
- There was evidence of poor verification practices, demonstrated by a high proportion of EPDs containing contradictory data.
- The EN 15804 harmonisation standard has not been entirely successful. The proportion of valid comparisons was much higher with EN 15804-compliant EPDs, but the overall level of comparability was still low.

European Standard EN 15804

In Europe, the PCRs for construction products are defined in a European standard EN 15804. As of December 2022, the most recent version of EN 15804 is:

EN 15804:2012+A2:2019/AC:2021 ‘Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products’

This standard was first published in 2012 and revised in 2019 to align the methods and reporting categories with the EU Product Environmental Footprint Product Category Rules (PEF-PCR). Subsequently, a minor change was made in 2021 to the freshwater eutrophication potential characterisation factor in order to correct an error in the reporting units.

The standard provides a description of how to conduct an LCA in order to produce an Environmental Product Declaration (EPD) for products, or services for the built environment. The EPD can report the environmental information as a declared unit (a weight, volume, or quantity of material with specified dimensions), or as a functional unit (quantified performance of a product/service system for use as a reference unit).

The purpose of providing a standard that defines core product category rules describing how to conduct an LCA and report on the outcomes is to provide verifiable and consistent data for an EPD, based on LCA; as well as verifiable and consistent product-related technical data, or scenarios, for the assessment of environmental performance.

The purpose of the EN 15804 standard is to allow for communication of the environmental information of construction products/services from business to business; and, subject to additional requirements, for the communication of the environmental information of construction products/services to consumers.

At first sight, the information contained in EPDs can be quite intimidating, so this section of the document will provide some basic principles for understanding and getting the best out of an environmental product declaration.

The main environmental indicator of interest is global warming potential (GWP) which is reported in units of kilograms carbon dioxide equivalents (kg CO_2e). In earlier versions of EN 15804 there was one entry for GWP, which is reported for all the different parts of the life cycle. The cradle to factory gate part of the life cycle is EPD modules A1-A3 (Table 1).

In the EPDs of many building products it is possible to find out the climate change impact associated with manufacturing the product by adding the values in modules A1-A3. Quite often, this is already done, or sometimes all three modules are aggregated and just reported as A1-A3, rather than separately.

Before we go onto considering how it is possible to make these comparisons, it is necessary to look at the changes that have been made to EN 15804. For the purposes of this document, only GWP will be discussed, although there have been other changes made, including new characterisation factors (impact categories).

- One of the most obvious changes for the latest version of EN 15804 (+A2 version), is the dividing of the global warming potential characterisation factor into fossil, biogenic and land use and land use change (luluc) categories. There are also specific requirements when reporting the biogenic GWP category for materials which contain sequestered atmospheric carbon (e.g., timber products). These are important changes and it is necessary to examine the new rules in more detail.
- The GWP-biogenic indicator accounts for GWP from removals of CO_2 into biomass from all sources except native forests, as transfer of carbon, sequestered by living biomass, from nature into the product system. This indicator also accounts for GWP from transfers of any biogenic carbon from previous product systems into the product system under study.
- Any carbon exchanges in native forests are declared in the category GWP-luluc. Native forests exclude short term forests, degraded forests, managed forest, and forests with short term or long-term rotations. Any carbon exchanges associated with land use change are also included.
- For timber products it is no longer allowed to report only for the life cycle modules A1-A3 (cradle to factory gate), but must also include modules C1-C4 and module D.
- It is not permitted to consider the storage of atmospheric carbon (biogenic carbon) as being permanent. It states in the standard (Section 6.3.5.5): ‘The degradation of a product’s biogenic carbon content in a solid waste disposal site shall be declared without time limit. The emission is treated as an emission of biogenic carbon dioxide.’ This means that the biogenic carbon content, which is reported as a negative value in module A1, has to be reported as a positive

value in module C4. Consequently, the sum of biogenic carbon storage over the whole reported life cycle is zero.

- Biogenic carbon in the declared product should be treated separately from biogenic carbon in the packaging and these two values are declared in a separate table in the EPD.

These are the requirements that are specified in EN 15804 when dealing with biogenic carbon, but some EPD program operators also have additional requirements.

Although the rules are quite specific in describing how biogenic carbon should be reported in an EPD, there are still potential problems when it comes to interpreting the declared values. Many EPDs show the sequestration of atmospheric carbon into the timber in the forest in module A1 (where this is reported separately). However, this is not reported the same way in different EPDs. If we consider the example where the declared unit is 1 m^3 of timber, The most common way of reporting the sequestered carbon is to calculate the quantity of stored carbon in the declared unit (taking account of moisture content). In EPDs where the stored carbon is declared separately (as is now a requirement), it is therefore relatively straightforward to calculate the GWP impact associated with processing from the declared GWP total for modules A1-A3. This can be done by subtracting the amount of carbon stored in the declared product (in kg CO_2e) from the GWP total value.

Global Warming Potential

Global warming potential is a measure of the radiative forcing arising from gaseous emissions associated with a product or service. GWP is measured in kg carbon dioxide equivalents, in which the radiative forcing of other gases (e.g., methane) is converted into an equivalent amount of carbon dioxide. The conversion factor for these gases varies, depending upon the timescale studied. The default calculations are based upon a timescale of 100 years (commonly referred to as GWP_{100}).

Global warming potential (GWP) of the timber products is shown in Appendix 1. In some cases, these data have been supplied in the EPD and in other, this has had to be inferred from the reported GWP, which combines both the GWP impact and the sequestered carbon in the timber product (where this is not stated, it has been calculated according to EN16449). It is unfortunate that the GWP impacts are not reported separately from the sequestered carbon in most EPDs. It is much better practice to report this data separately. It also gives the cement industry justification for including carbonation of cement in their GWP values, reducing transparency of the reporting process. In newer EPDs, which follow the latest version of EN15804, the stored atmospheric carbon is reported as biogenic carbon, but this entry may also show emissions of biogenic carbon (such as burning of sawmill residues) and cannot be guaranteed to report only stored atmospheric carbon in the timber product. This confusion is unfortunate.

Sequestered Carbon

The amount of carbon dioxide equivalents stored in the wood can be calculated from the formula given in the European standard EN 16449:

$P(CO_2) = (44/12) \times Cf \times [(\rho_\omega \times V_\omega)/(1+(\omega/100))]$

Where:

$P(CO_2)$ is the stored carbon reported as the equivalent in atmospheric carbon dioxide (kg CO_2 eq.)
Cf is the carbon fraction of the wood (0.5 is used as the default value)
ω is the moisture content of the wood on a dry basis
ρ_ω is the density of the wood (kg/m^3) at that moisture content
V_ω is the volume of the solid wood product at that moisture content

The default value of 0.5 for Cf should not be used for thermally modified wood, acetylated wood, or furfurylated wood. For TMT, the conversion factor will be higher than 0.5, since the C/OH ratio increases with thermal treatment. For acetylated and furfurylated wood, the weight of the wood also includes the weight of the modifying agent and this needs to be treated separately.

In the latest version of EN 15804:2012+A2:2019, it is mandatory to include a table stating the stored sequestered carbon in units of kgC, which can be readily converted to $kgCO_2e$ by applying the conversion factor $kgCO_2e = (44/12) \times kgC$. The number reported here may correspond with the biogenic carbon entry in the main table, or the LCA practitioner may also have counted biogenic carbon emissions (for example burning of biomass for heating kilns). If biogenic carbon also includes emissions, then this should be accounted for in module A1, where the sequestration of that carbon occurred.

Most EPD program operators also now require a separate entry where the biogenic carbon is not included, so that emissions of fossil-derived GHGs are now unambiguously reported.

Embodied Energy

The embodied energy of a material or product used in a structure or product is often defined as the primary energy used in the manufacture, which includes all the primary energy used in the production, as well as the primary energy used in the transport of materials and goods required for the production process. This definition relates to the initial embodied energy, which is related to the cradle to factory gate stage (modules A1-A3, EN 15804) of the product life cycle. In some definitions, the transport to construction site (A4) and the energy used on site for the erection or installation of the product (A5) is also included. The units used are generally MJ per unit mass, or volume, or per defined functional unit, although some workers report this as kWh (= 3.6 MJ). Transport of materials to site can have a major impact on the embodied energy of the construction materials.

The embodied energy is invariably reported according to the cumulative energy demand (CED) method, which states that the embodied energy is assessed as the primary energy used for the manufacture, use and disposal of an economic good (product or service), or which may be attributed to it with justification. The method distinguishes between non-renewable and renewable energy use. The cumulative energy demand (CED) represents the primary energy used (both direct and indirect) during the life cycle of a product (Huijbregts et al. 2006). This includes the energy consumed during the extraction, manufacturing and the disposal of the product and raw and auxiliary materials. Different methods for determining the primary energy demand exist. For example, the lower or higher heating values of primary energy sources may be used, the use of renewable energy resources may not be included or it may be reported separately. Fay and Treloar (1998) define primary energy as 'the energy required from nature (e.g., coal) embodied in the energy consumed by the purchaser (for example, electricity) and the energy sued by the consumer as 'delivered energy'. This means that a process using 1 MJ of electricity in one region of the world may have a different embodied energy compared to an identical process using 1 MJ of electrical energy in another part, because the grid mix in the two regions is different.

Dixit et al. (2012) noted that some research workers do not include renewable energy in their definition of embodied energy and also found that the use of different information sources and the failure to distinguish between primary or secondary energy could lead to errors as high as 40% when reporting embodied energy.

They concluded that there is a need to develop a common methodology to accurately determine the embodied energy associated with buildings and that there is a need to develop a complete and robust database of embodied energy information.

Different methods for determining the primary energy demand exist. For example, the lower or higher heating values of primary energy sources may be used, the use of renewable energy resources may not be included or it may be reported separately (as in EN15804). Primary energy is defined as 'the energy required from nature (e.g., coal) embodied in the energy consumed by the purchaser (for example, electricity) and the energy used by the consumer as 'delivered energy'. This means that a process using 1 MJ of electricity in one region of the world may have a different embodied energy compared to an identical process using 1 MJ of electrical energy in another part, because the grid mix in the two regions is different.

The failure to distinguish between primary or secondary energy can lead to errors as high as 40% when reporting embodied energy. Cabeza et al. (2013) note that there is a relationship between embodied energy and GWP for primary production, for some building components and that there is a link between embodied energy and cost of buildings, which is related to the energy intensity per unit GDP for that country.

It is necessary to define the meaning of primary energy, since it is not always clear that the primary energy has been used when the embodied energy is reported. The primary energy is defined as the energy measured at the natural resource level, i.e. the energy found in nature that has not been subjected to any conversion process through human intervention. This is the energy used to produce the end-use energy which includes the energy used in the extraction, transformation and distribution to the user (Fay et al. 2000). Measurements of embodied energy are only consistent if they are based upon primary energy. However, if delivered energy is used (e.g., based on meter readings at the sawmill), the results are misleading. Unfortunately, there is a lack of clarity and incomparability in the reporting of embodied energy (Dixit et al. 2010, 2012).

The inherent energy is the solar energy that is stored in the wood and is recoverable at the end of the product life. This property of bio-based materials is an important consideration when making choices for the built environment.

The embodied energy associated with the production of 1m^3 of product is shown in Appendix 2. In theory, this is less likely to be subject to errors in calculation compared with the GWP, since it is directly reported, there should also (theoretically) be fewer differences between each EPD for this parameter. The embodied energy values are calculated from the following entries in the EN15804-compliant EPDs:

PERE: Use of renewable primary energy excluding renewable primary energy resources used as raw materials
PENRE: Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials

The recoverable energy of the wood (also called inherent energy, or embedded energy) was calculated using the data in the entry:

PERM: Use of renewable primary energy resources used as raw materials

These numbers should be reliable and comparable, provided that:

- The LCA practitioners have calculated the embodied energy as primary energy, rather than delivered, or metered, energy.
- The renewable primary energy refers only to the product and has been calculated as the lower heating value of the dry wood equivalent weight.

It is important to distinguish between embodied energy, which is associated with the production of a good or service and the inherent (or embedded) energy, which is a physical property of the material. The terms embodied and embedded are sometimes confused in the literature. As noted previously, the embodied energy of a material is the primary energy that is associated with the extraction, processing and transportation of that material from the cradle to the factory gate. In contrast, the embedded energy of a material is a property of that material and can be directly measured. For example, the inherent energy in a wood product can be recovered at the end of its life cycle by incineration, whereas the inherent energy of concrete is zero. Since the incineration of wood produces carbon dioxide (a gas at room temperature) and water vapour (a liquid at room temperature), two possible values for the calorific content may be reported:

- Lower heating value (LHV) – this is the actual thermal energy recovered from the burning of wood.
- Higher heating value (HHV) – this is the measured recovered thermal energy, plus the energy of vaporization of water (this would be recovered in a condensing boiler).

In EN 15804, it is the lower heating value that must be reported.

https://support.simapro.com/s/article/How-to-calculate-EN-15804-A2-indicators-in-desktop-SimaPro

'*For PERM and PENRM impact categories, certain materials like wood, paper are allocated to PERM and materials like Nylon, Rubber, etc. are allocated to PENRM. In order to calculate this impact categories, their lower heating values (LHV) are obtained from www.phyllis.nl*.'

GWP and Service Life

A brief study was undertaken combining the GWP data with durability class of the product for Abodo Vulcan Timber (Durability Class 1 – above-ground life expectancy more than 40 years) compared with unmodified radiata pine (Durability Class 4 – above ground life expectancy 7 years). According to this information, the equivalent use of Vulcan in service would require a minimum of 5 replacements of the untreated radiata pine produced in NZD (S-P-05512).

EPD	Life expectancy (years)	GWP ($kgCO_2e/m^3$)	GWP-total ($kgCO_2e/m^3$)
S-P-05512	7	80	400
S-P-01543	40+	243	243

This is a very simplistic analysis that takes no account of the GWP impacts associated with the replacement, transport, disposal, etc., but merely examines the impact associated with direct substitution. Nonetheless, this shows that there is a clear advantage due to the extension of service life associated with the use of thermally modified timber in out-of-ground-contact situations.

When examining the performance of timber in service it is important to have knowledge of the service life so that this can be factored into life cycle costing (LCC) and life cycle analysis (LCA). In order to inform these choices, it is necessary to have reliable predictive models. The prediction of service life of timber products requires the use and interpretation of accelerated tests, where the risk factors, such as moisture content and temperature can be combined with timber durability indices to determine performance (Brischke et al. 2017, van Niekerk et al. 2021).

There is considerable variation in the predicted service life for timber products in external environments and many factors can influence the performance, with wide variations reported. For example, Silva and de Brito (2021) quote estimated service lives of timber cladding varying from 'more than 10 years' to 'more than 60 years'. These uncertainties will inevitably negatively impact the accuracy of LCC and LCA. This may cause specifiers to choose other materials which have more predictable performance.

Estimates of service life can be made by using accelerated tests and applying the appropriate correction factors (Gupta et al. 2011). Such models are based upon the known durability properties of the material, environmental factors and design considerations. Simple approaches to determining the service life of building elements include the factor method, as described in ISO 15686, which are readily applied (Silva and Prieto 2021). However, factor-based methods have been criticised because they do not adequately consider non-linear relationships between such things as detail design and climatic variation.

More realistic and complex predictive tools adopt probabilistic approaches, which may be too complex to apply in real-life situations. In both cases, the relevant information may not be available, or available in sufficient detail to make accurate predictions. In Europe, the WOODEXTER project developed a useable performance-based model considering climatic conditions and material durability. In this model, a limit state was defined which represents the onset of wood decay. Using this approach, the exposure can be expressed in an algorithm that takes into account the local and global climate, the design of the element and the surface treatment employed.

Meanwhile, the material resistance can be represented as a response to the exposure conditions independent of the design, using a dose-response model. These attempts to predict service life by applying dose response models consider wood moisture content and temperature as factors influencing wood decay. However, the fluctuating moisture content of cladding boards in real-life service conditions do not necessarily reflect assumptions made about durability, which are based upon laboratory conditions of constant moisture. Furthermore, differences in moisture content in exterior cladding depend on factors such as roof overhang and distance from ground and these details must be incorporated into the models (Hill et al. 2022).

Tropical hardwoods

No EPDs have been found for tropical hardwood species and there is little LCA data that is publicly available.

A report dated April 6th 2020 by Rupert Oliver of Forest Intelligence Ltd. for IDH-Sustainable Trade Initiative made the following statements:

'The reality is that calculating an accurate carbon footprint for certified timber is near impossible—there simply isn't enough data. Certification frameworks don't currently collect the data needed to facilitate carbon accounting, and there is a great deal of uncertainty involved in scaling existing one-off carbon assessments of timber operations to a global scale.'

The most recent IDEMAT dataset by Delft University of Technology is available at www.ecocostvalue.com. The database contains information regarding different tropical timbers, but the reliability of these data is uncertain. The GWP-GHG and embodied energy (CED) data reported in the 2023 IDEMAT database is reproduced below. This is for as-delivered to Rotterdam.

Product	Density (kg/m^3)	GWP ($kgCO_2e/m^3$)	CED (MJ/m^3)
Sapeli (FSC)	650	161	13914
Sapeli (nat)	650	2403	13914
Acetylated radiata pine	510	236	25569
Radiata pine	450	181	10900

Notes: nat = natural forest, these data are not comparable with EPD data.

Useful websites and publications (accessed 24/08/2023)

As noted above, there is a report on the carbon footprint of tropical timber hosted at the IDH-Sustainable Trade Initiative website: https://www.idhsustainabletrade.com/publication/carbon-footprint-of-tropical-timber/

There are useful links related to the marketing of verified sustainable tropical timber which can be accessed at https://www.europeansttc.com/marketing/ hosted by the European Sustainable Tropical Timber Coalition.

EPDs of tropical hardwood products (decking, bulkheads) can be downloaded from Centrum Hout https://www.houtindegww.nl/technische-info/lca/ but there is no EPD for sawn wood products.

There is an impact calculator which has been developed by FSC Nederland for determining the environmental costs of different timber species, but the method of calculation is not explained. It can be accessed at http://impacttool.fsc.nl/

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van Niekerk, P.B., Brischke, C., Niklewski, J. (2021) Estimating the service life of timber structures concerning risk and influence of fungal decay—a review of existing theory and modelling approaches. Forests, 12:588.

EN 15804 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

EN 16449 Wood and wood-based products - Calculation of the biogenic carbon content of wood and conversion to carbon dioxide.

EN 16485 Round and sawn timber – Environmental product declarations – Product category rules for wood and wood-based products for use in construction.

Appendices

Appendix 1: GWP data reported for modules A1-A3 (forest to factory gate) (declared unit 1 m^3) (GWP in kgCO_2 eq.)

EPD reg. no.	Date	Country	Description	Density (kg/m^3)	MC (%)	TOTAL	Seq.	GWP-GHG
S-P-00997	2019	NZL	Sawn dried radiata (WPMA)	488	11.6	-747	-798	+51
S-P-00997	2019	NZL	Sawn dried planed radiata (WPMA)	486	11.6	-728	-795	+69
S-P-01543	2020	NZL	TMT Vulcan radiata sawn (Abodo)	420	7	-535	-758	+224
S-P-01543	2020	NZL	TMT Vulcan radiata sawn planed (Abodo)	420	7	-516	-758	+243
S-P-01718	2019	GBR	Brimstone Ash (Vastern)	631	5	-704	-1110	+406
S-P-01718	2019	GBR	Brimstone Sycamore (Vastern)	571	5	-639	-1010	+371
NEPD-376-262-EN	2015	NLD	Accoya (radiata) (Accys)	510	4	-433	-944	+511
Agrodome[1]	2022	NLD	Accoya (radiata) (Accys)	515	4	+127	-802	+810
EPDIE-22-107	2022	IRL	Tricoya Extreme (Medite)	720		+861	-840[2]	+1700

[1]Not registered as an EPD, but follows the EN 15804 PCR, [2]Declared as biogenic carbon and may also include emissions

Appendix 2: Embodied energy and inherent energy data for modules A1-A3 (forest to factory gate) (declared unit 1 m^3)

EPD registration number	Date	Country	Description	PERE (MJ)	PENRE (MJ)	Embodied Energy (MJ)	PERM (MJ)
S-P-00997	2019	NZD	Sawn dried radiata pine	4200	552	4752	8260
S-P-00997	2019	NZL	Sawn dried planed radiata (WPMA)	5330	720	6050	8240
S-P-01543	2020	NZL	TMT Vulcan radiata sawn	4200	2970	7170	7560
S-P-01543	2020	NZL	TMT Vulcan radiata sawn planed (Abodo)	4740	3230	7970	7560
S-P-01718	2019	GBR	Brimstone Ash	22200	6480	28680	9250
S-P-01718	2019	GBR	Brimstone Sycamore	18100	5810	24580	10400
NEPD-376-262-EN	2015	NLD	Accoya (radiata)	847	14559	15406	6574
Agrodome[1]	2022	NLD	Accoya (radiata)	802	19700	20500	0
EPDIE-22-107	2022	IRL	Tricoya Extreme	5570	38400	43970	0

[1]Not registered as an EPD, but follows the EN 15804 PCR

Embodied energy is the sum of PERE (renewable primary energy as an energy source) and PENRE (non-renewable primary energy as an energy source). See text for a fuller explanation.

PERM is the primary renewable energy of the raw material and should be equal to the inherent energy content of the wood (calorific content), lower heating value. The recoverable energy content of the wood is a function of the density and the moisture content (19-21 MJ/kg dry mass of wood), according to EN 15804 this should be reported as lower heating value.