JCH INDUSTRIAL ECOLOGY LIMITED

EPD REVIEW SOLID AND MODIFIED WOOD

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Callum Hill BSc, PhD, (FIMMM)

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

JCH Industrial Ecology Ltd was engaged by Abodo Wood Ltd to conduct a survey of published EPDs of unmodified and modified wood, comparing global warming potential (GWP), sequestered atmospheric carbon, embodied energy and inherent energy. A total of 42 timber products have been compared, divided into sawn (green), sawn (dried), sawn and planed, sawn, planed and finger-jointed, as well as modified wood. The following categories have not been analysed: glulam, cross-laminated timber, wood-based panels (e.g., particleboard, MDF, OSB, plywood).

- A relationship between embodied energy and GWP exists, but there are significant outliers.
- In all cases, the atmospheric carbon stored in the product exceeds the global warming potential (carbon footprint).
- Some errors have been identified in the EPDs.

Comparison of EPDs

Relationship between embodied energy and GWP

The embodied energy data and GWP data for the published timber EPDs are shown in Appendix 1. The same data are shown in graphical form in Figure 1.

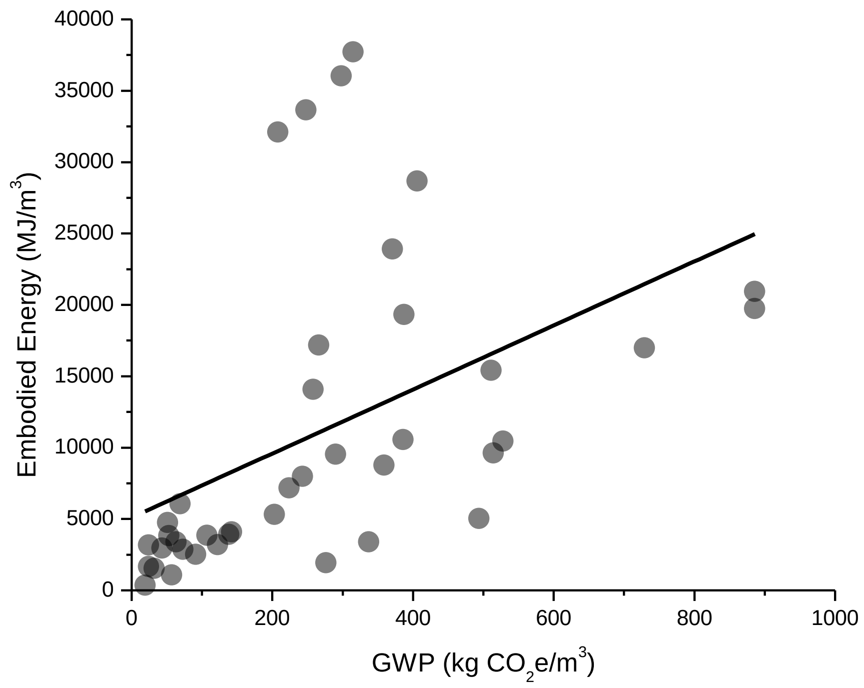

Figure 1: Relationship between embodied energy and GWP impact per m³ of timber product.

A linear fit through all of the data points (concatenate) is also shown. There should be a loose correlation between the embodied energy and the GWP impact, with higher GWP impact expected for an increase in embodied energy.

Deviations from the relationship between embodied energy and GWP can be explained by the energy mix employed for the processes. For example, if the grid energy mix has a high fossil fuel content, higher GWP impacts occur per unit of electrical output (Appendix 3). Other reasons for the deviations may be related to the use of biomass for energy, for which the LCA may have accounted biogenic emissions as zero.

The data for unmodified wood is shown in Figure 2.

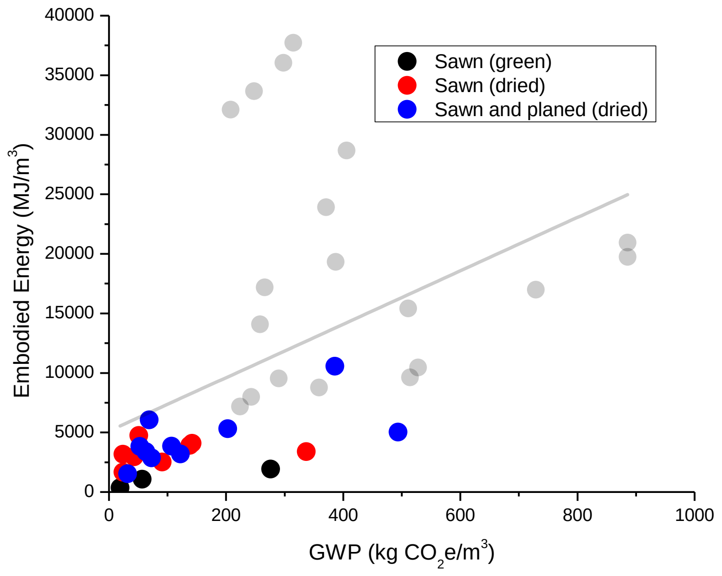

Figure 2: Relationship between embodied energy and GWP impact for unmodified wood

In principle, there should be an increase in both embodied energy and GWP emissions as the degree of wood processing increases. This trend is not readily apparent in the data, but there are some obvious outliers which have considerably higher GWP compared with the main group. These belong to wood processed in Australia, where the higher carbon footprint of the Australian grid mix is presumably the main cause of the higher GWP values. One data point is associated with the production of sawn and planed Siberian larch and the higher embodied energy (10566 MJ/m^3) and GWP (386 kgCO$_2$e/m^3) is due to the long transport distances involved.

A comparison of the relationship between the GWP and embodied energy for the thermally modified woods is shown in Figure 3.

The most significant deviations from the linear fit are for the TMT Lunawood and TMT Brimstone data, with substantially higher embodied energies being reported compared with the TMT Estonia, TMT Vulcan. However, the GWP impacts for the TMT Lunawood and TMT Brimstone are much lower than would be expected from the linear correlation and the stated embodied energies.

In principle, similar processes should have similar embodied energies and the TMT Lunawood and, to a lesser extent, the TMT Brimstone exhibit higher embodied energies than would be expected from the other TMT data.

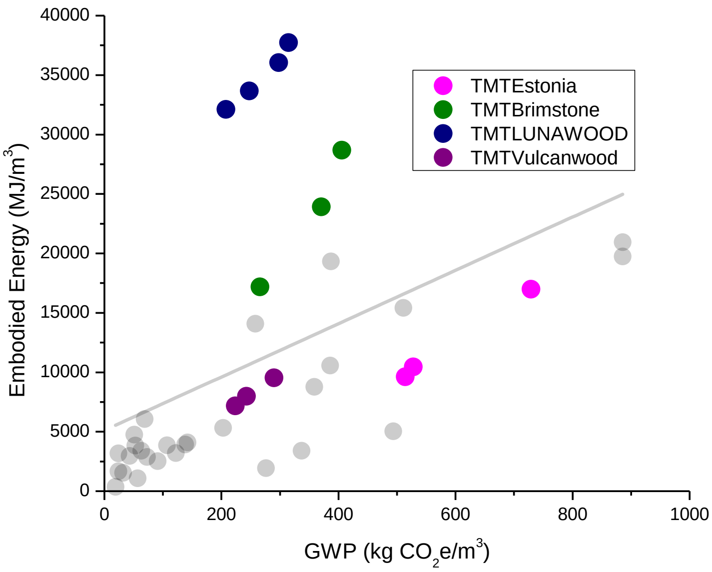

Figure 3. Relationship between embodied energy and GWP impact for thermally modified timber (TMT)

The Vulcan TMT exhibits the lowest embodied energy and GWP of the studied product group, which can be at least partly attributed to the low GWP associated with the New Zealand electricity grid being dominated by renewable primary energy sources.

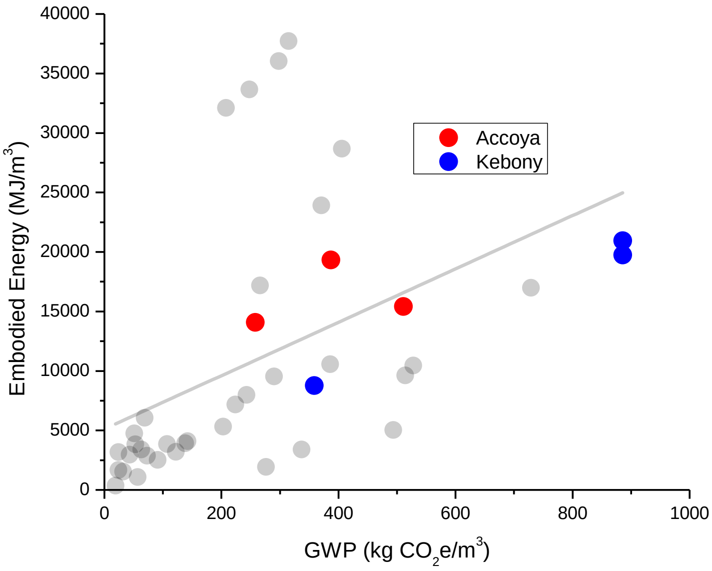

Figure 4: Relationship between embodied energy and GWP for Accoya and Kebony products

The relationship between embodied energy and GWP for Accoya and Kebony products is shown in Figure 4. The EPD for Accoya lists three products which use beech, southern yellow pine and radiata pine as the wood source. Of these, only Accoya from radiata pine is in production. The commercial products are shown in Figure 5.

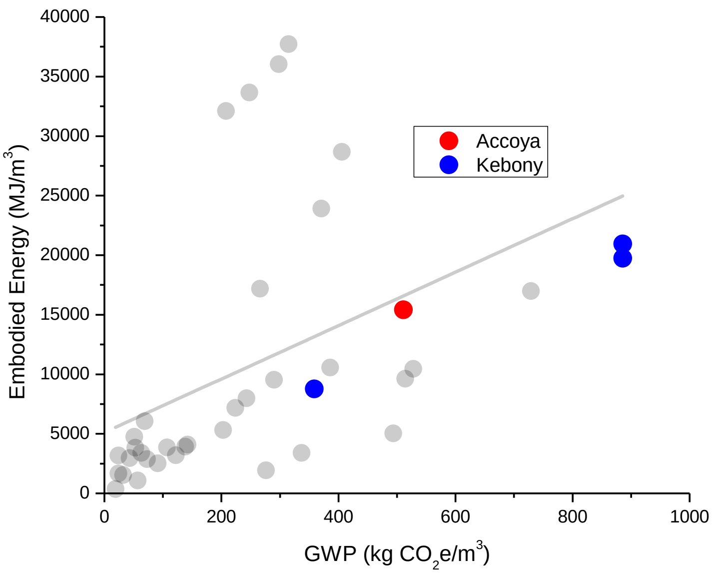

Figure 5: EPD data for commercial Accoya and Kebony products

A comparison of timber products derived from New Zealand-grown radiata pine was made and results are shown in Figure 6. The products show an increase in embodied energy and GWP with further processing.

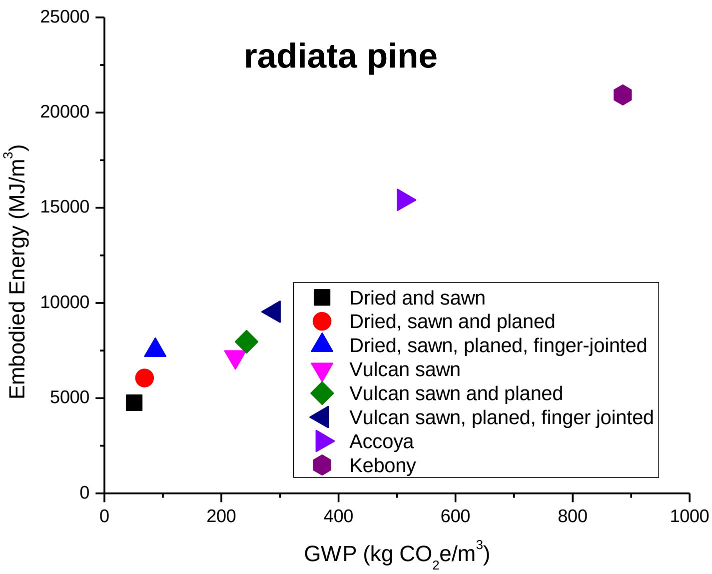

Figure 6: Relationship between embodied energy and GWP for all radiata pine products

Embodied energy and inherent energy

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. A comparison of the embodied energy and the inherent energy of the radiata pine products is shown in Figure 7.

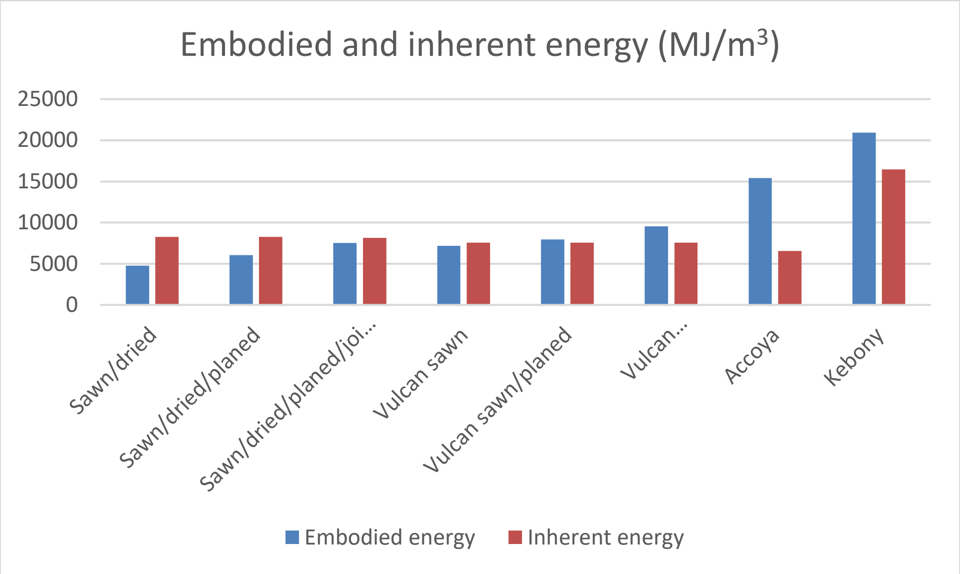

Figure 7: Embodied energy and inherent (recoverable energy) in radiata pine products

There is an increase in embodied energy as the amount of processing this that wood is subjected to increases, plus there is the embodied energy of the chemicals used for the Accoya and Kebony modifications, as well as the process energy. The inherent energy of the Vulcan TMT is lower than the unmodified wood, due to a lower density, even though the higher relative carbon content increases the calorific content per unit weight of product. The increased inherent energy of the Kebony is due to the energy content of the furfuryl polymer as well as the wood itself. The inherent energy content of the Accoya is lower than unmodified wood.

The inherent and embodied energy associated with the different TMT products is shown in Figure 8.

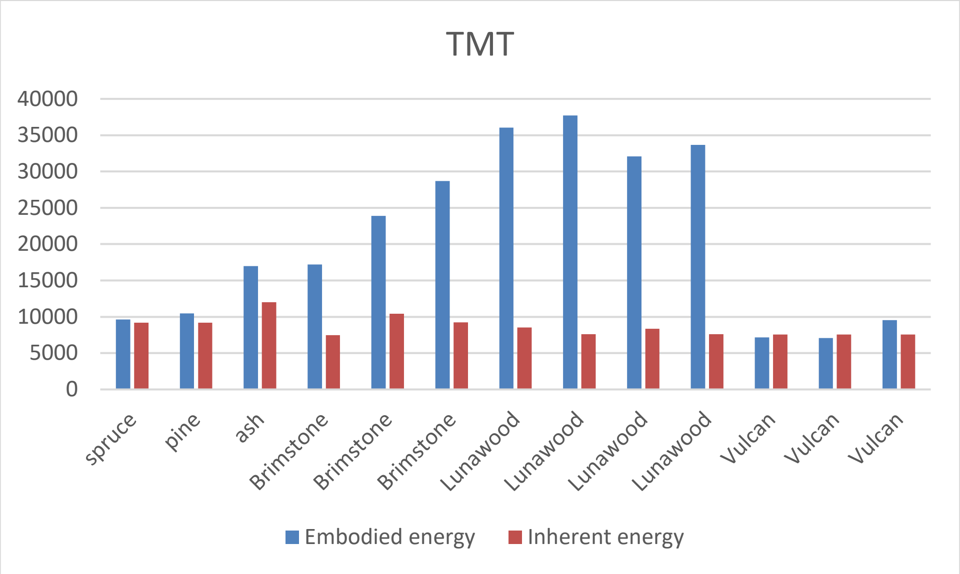

Figure 8: Inherent and embodied energy associated with the TMT products

Sequestered carbon in radiata pine and GWP

A comparison of the GWP impact vs. the stored atmospheric carbon for radiata pine products is shown in Fig. 9. The stored carbon in 1 m3 of radiata pine is in the region of 790-800 kgCO_2e, but in the Accoya and Kebony products appears to be anomalously high.

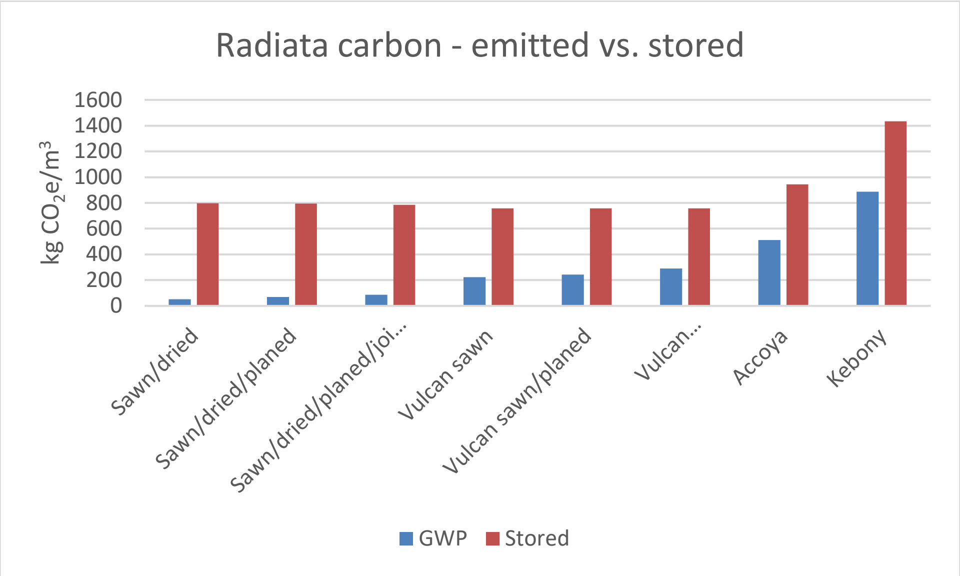

Figure 9: Comparison of the GWP impact vs. stored carbon for radiata pine products

The relevant EPDs were examined to determine how the calculations for sequestered carbon were made:

<u>NEPD-376-262-EN Accoya radiata</u>

'The declared unit is 1 m^3 of Accoya planed timber'

'The carbon sequestration has been taken into account of the finished product: 1.85 kg CO_2 per kg Accoya wood (corresponding to 944 kg CO_2 per m^3 Radiata pine, 999 kg CO_2 per m^3 Scots pine and 1397 kg CO_2 per m^3 Beech).'

The following densities are quoted:

'The results are given for 3 Accoya products per m^3:
- Accoya from Radiata pine from New Zealand (510 kg/m^3)
- Accoya from Scots pine from Sweden (540 kg/m^3)
- Accoya from Beech from Germany (Schwarzwald) (755 kg/m^3)'

The moisture contents are not quoted and it is apparent that these densities refer to the Accoya product, rather than the unmodified wood. According to the Accoya wood Information Guide[https://www.accoya.com/app/uploads/2020/04/Wood-Information-Guide-English.pdf], the density of Accoya made from radiata pine at 65% RH and 20°C is 512+/-80 kg/m^3.

In order to understand how the sequestered carbon value was arrived at, a density of 510 kg/m^3 at a moisture content of 0% was entered into the EN 16449 calculation (assuming a carbon content of 0.5). This gives a value for stored atmospheric carbon of 935 kg/m^3, close to the quoted value. However, the sequestered carbon should not be calculated using the density of the acetylated wood, since this contains acetyl groups from the reaction of wood with acetic anhydride, which is derived from fossil carbon. The correct procedure would be to calculate the weight of unmodified wood in the acetylated wood (Accoya, minus weight of added acetyl). It is understood that NEPD-376-262-EN is currently being revised.

NEPD-407-287-EN Kebony Clear radiata

'The mass of the green wood is 480 kg/m^3, and the moisture content is assumed to be 12% as recommended by the standard. The biogenic CO_2 uptake from the wood is thus 785,71 kg CO_2.The biogenic carbon uptake in the furfuryl alcohol is calculated based on the stoichiometric formula for furfuryl alcohol, which is $C_5H_6O_2$. This gives a molar mass of 98/mol of which Carbon accounts for 61.2% of this mass. A Kilo furfuryl alcohol thus contains 612 grams of carbon, which in turn results in emissions of 2266 grams of CO_2 when released. 1 m^3 of Kebony Clear (Radiata) contains 286.6 kg of furfuryl alcohol, which represents the biogenic carbon uptake of 590.4 kg. The total Biogenic CO_2 uptake is thus as following: 785.71 CO_2 + 590.4 kg CO_2 =1435.14 kg CO_2.'

This calculation is reasonable.

The GWP and stored carbon contents associated with the TMT products is shown in Figure X.

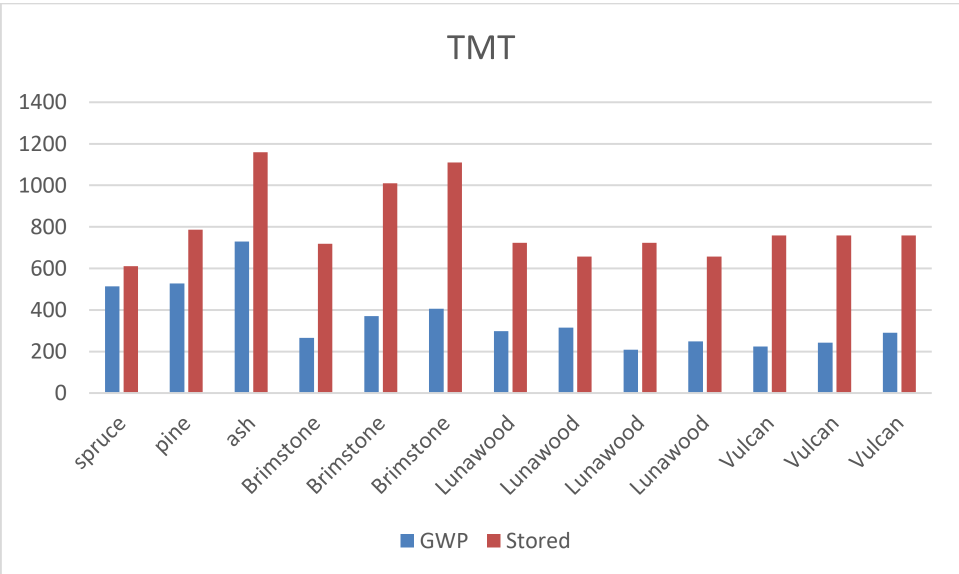

Figure 10: GWP and stored carbon in TMT products

In all cases the amount of atmospheric carbon stored in the TMT products exceeds that associated with process emissions. The final plot (Fig. 11) combines these two values, with GWP being recorded as a positive emission and sequestered atmospheric carbon being reported as a negative number. This shows that the value is negative for all TMT products. Higher wood density gives a larger negative value.

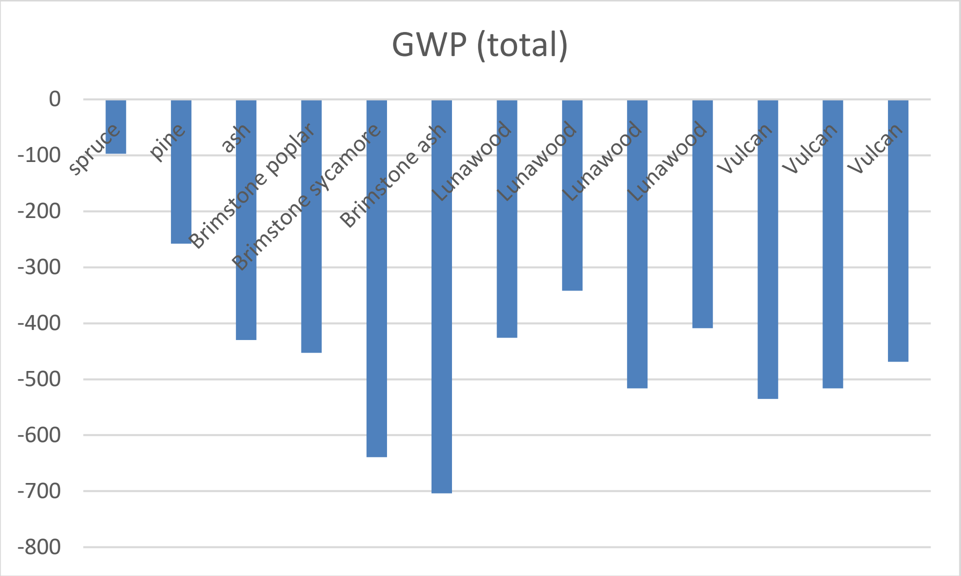

Figure 11: Total GWP for thermally modified timber products

Background 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 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 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 fulfilled:

- 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, although this is not compulsory. 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 in Table 1.

Table 1: Different life cycle stages defined in EN 15804

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). These are listed in Table 8. The publication of this standard ensures harmonisation of core PCRs for building products in Europe. It is mandatory to report stages A1-A3, with the other stages being included for any reporting beyond cradle to factory gate.

PCRs have been developed by different organisations which have set up EPD programmes (examples in Europe include the International EPD® system based in Sweden and the Institut Bauen und Umwelt in Germany). Since the introduction of ISO 14025, there has been a proliferation of EPD systems, with their own PCRs. ISO 14025 encourages the operators of EPD programmes to harmonise their methods and PCRs and in Europe this has resulted in the creation of ‘ECO’ a platform for rationalising EPDs, involving 11 EPD operators within Europe. This involves mutual recognition of EPDs, and the creation of common PCRs, working from agreed core

PCRs (such as EN 15804 in the built environment). EN 15804 has been revised recently to make the PCR consistent with the recently introduced EU Product Environmental Footprint scheme.

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.

The objective of environmental labels and declarations is to provide accurate and verifiable information on the environmental performance of goods and services, with the objective of stimulating continuous market-driven environmental improvement (ISO 14020). The international standard ISO 14024 defines Type I environmental labels, which are certificates (ecolabels) that are issued by an independent, third party verification body. Examples of Type I ecolabels include single-attribute labels about wood sourced from forests that are managed sustainably (e.g., FSC, PEFC) and there are many examples listed on the ecolabel website. Type II environmental labels are defined in ISO 14021; these are self-declared environmental labels. Examples include statements regarding recyclability, compostability, etc.

Global Warming Potential

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 in some cases. In other cases, the biogenic carbon category is used to report emissions of biogenic carbon only. It is also possible that this value can include both emissions of biogenic carbon dioxide, as well as stored atmospheric carbon. This confusion is unfortunate.

The calculated GWP value for the Austrian production is very low and the values for Australian production are very high, which could be explained by the high GWP impact of the Australian electricity grid. The Norwegian EPDs for sawn, and sawn and planed, have a much lower GWP impact compared with the UK EPDs, which makes sense, given the low fossil carbon intensity of the Norwegian grid. Note that the energy required for planing results in a higher GWP impact, compared to sawing only, but the size of this impact is heavily dependent upon the electricity grid primary energy mix (see Appendix 3). EPD-Norge quote 0.012 kg CO_2 eq. per MJ (=43.2 g CO_2 eq. per kWh) for Norwegian electricity production, which is composed of a primary energy mix of 96% hydro, 2.5% thermal and 1.4% wind. The Australian grid mix GWP impact is quoted in S-P-00560 as being 1,000 g CO_2 eq. per kWh and is composed of 90% fossil fuel energy and 10% biomass. The New Zealand grid mix is dominated by renewable energy sources (primarily hydro and geothermal) resulting in an emission intensity of 100 g CO_2 eq. per kWh. The UK grid mix GWP impact in 2009 was 488 g CO_2 eq. per kWh (Source: Defra 2011 Guidelines to Defra/DECC's GHG conversion factors for company reporting).

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}).

Sequestered Carbon

Sequestered carbon in the timber products is shown in Appendix 1.

The amount of carbon dioxide equivalents stored in the wood can be calculated from the formula given in the European standard EN16449:

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

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.

Embodied Energy

The embodied energy associated with the production of 1m^3 of sawn softwood 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.

The embodied energy of a material or product used in a structure or product is the primary energy used in the manufacture, which includes all of the 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. This would be the case for Abodo products transported to Europe when compared with European-produced TMT. The analysis in this report if for A1-A3 life cycle stages only.

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.

References

Cabeza, L., Rincón, L., Vilariño, V., Pérez, G., Castell, A. (2014) Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review. Renewable and Sustainable Energy Reviews, 29, 394-416.

Gelowitz, M., McArthur, J. (2017) Comparison of type III environmental product declarations for construction products: Material sourcing and harmonization evaluation. Journal of Cleaner Production, 157, 125-133.

Appendices

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

EPD registration number	Date	Country	Description	Density (kg/m^3)	MC (%)	TOTAL (reported)	Sequestered	GWP (calculated)	GWP (reported)
Wood for Good[1]	2014	GBR	Fresh sawn softwood	672	60	-713	-770[2]	+57	
S-P-00561	2017	AUS	Fresh sawn hardwood	768	26	-851	-1118[2]	+267	
EPD-EGG-20140246-IBA2-EN	2018	AUT	Sawn timber green	740	70	-779	-798[2]	+19	
Wood for Good[1]	2014	GBR	Sawn dried softwood	483	15	-679	-770[2]	+91	
Wood for Good[1]	2014	GBR	Sawn dried hardwood	698	12	-878	-902	+24	
NEPD 307 179 EN	2015	NOR	Sawn dried softwood	450	15	-672	-715	+43	
S-P-00560	2017	AUS	Sawn dried softwood	551	12	-760	-902[2]	+142	
S-P-00561	2017	AUS	Sawn dried hardwood	735	10	-888	-1225[2]	+337	
EPD-EGG-20140247-IBA2-EN	2017	AUT	Sawn timber dried softwood	507	15	-784	-808	+24	
S-P-01325	2018	SWE	Sawn dried softwood	455	16	-577	-719[2]		+138
S-P-00997	2019	NZD	Sawn dried radiata pine	488	11.6	-747	-798		+51
13CA24184.102.1	2013	USA	Dried planed softwood lumber	434	0		-795		+73
NEPD 00247N	2014	DNK	Sawn dried planed Siberian larch	650	18	-624	-1010	+386	
(BRE) 000124	2017	GBR	Sawn dried planed softwood	479	15	-712	-764	+52	+107
S-P-00560	2017	AUS	Sawn + dressed dried softwood	551	12	-699	-902[2]	+203	
S-P-00561	2017	AUS	Sawn + dressed dried hardwood	735	10	-731	-1225	+494	
Wood for Good[1]	2014	GBR	Sawn dried planed softwood	482	15	-646	-768	+122	
NEPD 308 179 EN	2015	NOR	Sawn dried planed softwood	420	17	-607	-660	+53	
S-P-00997	2019	NZD	Sawn dried planed radiata	486	11.6	-728	-795		+69
S-P-00997	2019	NZD	Sawn dried planed jointed radiata	475	10.5	-697	-784		+87
S-P-02153	2020	CZE	Sawn dried planed jointed softwood	450	15	-685	-717		+32
4788424634.102.1	2020	USA	Dried planed softwood lumber	460	15	+63[3]	-733[2]		+63
NEPD 00259N	2014	EST	TMT spruce	350	5	-97	-611	+514	
NEPD 00259N	2014	EST	TMT pine	450	5	-258	-786	+528	
NEPD 00260N	2014	EST	TMT ash	670	6	-430	-1159	+729	
S-P-01718	2019	GBR	TMT (Brimstone) poplar	409	5	-453	-719	+266	
S-P-01718	2019	GBR	TMT (Brimstone) sycamore	571	5	-639	-1010	+371	
S-P-01718	2019	GBR	TMT (Brimstone) ash	631	5	-704	-1110	+406	
RTS_44_19	2019	FIN	TMT Thermo-D Lunawood rough	430	5	-426	-724	+298	
RTS_44_19	2019	FIN	TMT Thermo-D Lunawood planed	390	5	-342	-657	+315	
RTS_44_19	2019	FIN	TMT Thermo-S Lunawood rough	430	5	-516	-724	+208	

RTS_44_19	2019	FIN	TMT Thermo-S Lunawood planed	390	5	-409	-657	+248
S-P-01543	2020	NZL	TMT Vulcan radiata sawn	420	7	-535	-758	+224
S-P-01543	2020	NZL	TMT Vulcan radiata surfaced	420	7	-516	-758	+243
S-P-01543	2020	NZL	TMT Vulcan radiata finger-jointed	420	7	-469	-758	+290
NEPD-376-262-EN	2015	NLD	Accoya (radiata)	510	4	-433	-944	+511
NEPD-376-262-EN	2015	NLD	Accoya (Scots pine)	540	4	-741	-999	+258
NEPD-376-262-EN	2015	NLD	Accoya (beech)(	755	4	-1010	-1397	+387
NEPD-407-287-EN	2016	NOR	Kebony Clear (radiata)	480	12	-549	-1435[4]	+886
NEPD-408-287-EN	2016	NOR	Kebony Clear (SYP)			-646	-1532[4]	+886
NEPD-410-288-EN	2016	NOR	Kebony character (Scots pine)			-738	-1097[4]	+359

[1]Not registered as an EPD, but follows the EN 15804 PCR
[2]data not supplied in the EPD, calculated using EN16449
[3]Not clear how this value is calculated
[4]Includes biogenic carbon in the furfuryl polymer

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)
Wood for Good[1]	2014	GBR	Fresh sawn softwood	34	1040	1074	8090
S-P-00561	2017	AUS	Fresh sawn hardwood	111	1810	1921	11300
EPD-EGG-20140246-IBA2-EN	2018	AUT	Sawn timber green	97	250	347	8050
Wood for Good[1]	2014	GBR	Sawn dried softwood	853	1650	2503	8120
Wood for Good[1]	2014	GBR	Sawn dried hardwood	328	2840	3168	11300
NEPD 307 179 EN	2015	NOR	Sawn dried softwood	2270	685	2955	7410
S-P-00560	2017	AUS	Sawn dried softwood	2480	1610	4090	9290
S-P-00561	2017	AUS	Sawn dried hardwood	879	2510	3389	12600
EPD-EGG-20140247-IBA2-EN	2017	AUT	Sawn timber dried softwood	1330	330	1660	8160
S-P-01325	2018	SWE	Sawn dried softwood	3170	748	3918	6750
S-P-00997	2019	NZD	Sawn dried radiata pine	4200	552	4752	8260
13CA24184.102.1	2013	USA	Dried planed softwood lumber	1640	1228	2868	
NEPD 00247N	2014	DNK	Sawn dried planed Siberian larch	3724	6842	10566	9180
(BRE) 000124	2017	GBR	Sawn dried planed softwood	2270	1570	3840	8440
S-P-00560	2017	AUS	Sawn + dressed dried softwood	3050	2260	5310	9290
S-P-00561	2017	AUS	Sawn + dressed dried hardwood	1190	3840	5030	12600
Wood for Good[1]	2014	GBR	Sawn dried planed softwood	1060	2130	3190	8080
NEPD 308 179 EN	2015	NOR	Sawn dried planed softwood	2930	902	3832	6840
S-P-00997	2019	NZD	Sawn dried planed radiata	5330	720	6050	8240
S-P-00997	2019	NZD	Sawn dried planed jointed radiata	6530	991	7521	8140
S-P-02153	2020	CZE	Sawn dried planed jointed softwood	1050	472	1522	7500
4788424634.102.1	2020	USA	Dried planed softwood lumber	2381	1000	3381	10959
NEPD 00259N	2014	EST	TMT spruce	2184	7426	9610	9180
NEPD 00259N	2014	EST	TMT pine	2761	7697	10458	9180
NEPD 00260N	2014	EST	TMT ash	6678	10302	16980	11990
S-P-01718	2019	GBR	TMT (Brimstone) poplar	13000	4180	17180	7460
S-P-01718	2019	GBR	TMT (Brimstone) sycamore	18100	5810	23910	10400
S-P-01718	2019	GBR	TMT (Brimstone) ash	22200	6480	28680	9250
RTS_44_19	2019	FIN	TMT Thermo-D Lunawood rough	30782	5270	36052	8353
RTS_44_19	2019	FIN	TMT Thermo-D Lunawood planed	31163	6565	37728	7604
RTS_44_19	2019	FIN	TMT Thermo-S Lunawood rough	27924	4177	32101	8354
RTS_44_19	2019	FIN	TMT Thermo-S Lunawood planed	28483	5174	33657	7605
S-P-01543	2020	NZL	TMT Vulcan radiata sawn	4200	2970	7170	7560
S-P-01543	2020	NZL	TMT Vulcan radiata surfaced	4740	3230	7970	7560
S-P-01543	2020	NZL	TMT Vulcan radiata finger-jointed	5680	3850	9530	7560
NEPD-376-262-EN	2015	NLD	Accoya (radiata)	847	14559	15406	6574
NEPD-376-262-EN	2015	NLD	Accoya (Scots pine)	932	13137	14069	10372
NEPD-376-262-EN	2015	NLD	Accoya (beech)(	1256	18069	19325	7596
NEPD-407-287-EN	2016	NOR	Kebony Clear (radiata)	5576	15354	20930	16476

NEPD-408-287-EN	2016	NOR	Kebony Clear (SYP)	6407	13335	19742	17473
NEPD-410-288-EN	2016	NOR	Kebony character (Scots pine)	3078	5691	8769	12302

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

Appendix 3: GWP Impacts of electricity production

APPENDIX 1a: GWP impact of different primary energy sources to electricity production (Source: Parliamentary Office of Science and Technology, Postnote No. 268, October 2006).

Primary energy source	GWP (g CO_2 eq. per kWh)
Coal	>1000
Oil	~650
Gas	~500
Photovoltaics	~58
Wind	~5
Hydro (storage)	~10-30
Hydro (run of river)	<5
Nuclear	~5