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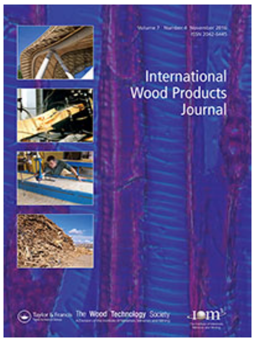

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The environmental impact of wood compared to other building materials

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One of the positive aspects of using wood in construction is the environmental benefits that this can potentially bring. However, manufacturers of all construction products and materials make claims about the 'environmental friendliness' of their products, making it exceedingly difficult for the end user to make informed choices about the advisability of using one product over another. This study presents an analysis of the published environmental product declarations of timber products (fibreboard, particleboard, oriented strandboard, glulam/laminated veneer lumber, sawn and dried timber) and compares this data with that published in the widely available and quoted University of Bath Inventory of Carbon and Energy database. Comparison is also made with some common non-biogenic building materials (concrete, brick, cement and steel).

Keywords: Global warming potential; Environmental product declaration; Wood; Building materials

Introduction

The environmental impacts associated with goods and products are assuming greater importance in informing choices of materials for use in the built environment. Life cycle assessment (LCA) is a tool that has been developed in order to analyse and quantify the environmental burdens associated with the production, use and disposal of a material or product and is a popular way of quantifying this information (Hill 2011). A hugely important issue is the impact of anthropogenic gas emissions upon the climate. One of the major advantages of the use of timber as a construction material is the ability to store significant amounts of atmospheric carbon for long periods of time in the built environment (Hill and Norton 2014).

The environmental impacts associated with any process of interest are attributed to a 'declared unit' or a 'functional unit'. A functional unit is a product that has a specified function, such as a window, or door, or a wall element, of a specific size. A declared unit is one where the function is not known or specified, e.g. 1 m^2 of a board product of specified thickness from a factory. When making correctly informed choices comparing different materials or products, it is very important to conduct the analysis on the basis of a functional unit rather than a declared unit. However, from the point of view of building up an LCA or environmental product declaration (EPD) for a functional unit, the information for various declared units is used as primary data. For a 'cradle to factory gate' LCA, the data are reported for a declared unit, but if other life cycle stages (e.g. in-service stage) are also included in the analysis, then a functional unit is used for reporting. The analyses in this paper are given for specified declared units (1 kg of product) and for cradle to factory gate only.

The collection and analysis of data for LCA invariably leads to issues regarding commercial confidentiality, which can cause problems, especially when the LCA has to meet adequate levels of transparency in order to be credible. In many cases, the LCA will include other stages, such as transport and installation, the use phase and ultimately, disposal. In some situations, the information for these other stages in the life cycle can be obtained relatively easily, in others it may require assumptions of varying accuracy/reliability to be made. There is a wide variety of choices to be made over what functional/declared units are to be studied and what impact categories are to be included in the LCA. This makes comparability between products problematical and there is considerable potential for uncertainties to creep into LCA, even when they are performed with the best of intentions. Nevertheless, considerable progress has been made in this field in the past decade.

Perhaps one of the most significant developments in reporting on the environmental impacts associated with products and services has been the introduction of EPDs which can be used (in principle) to compare the environmental performance of different products. In order to develop a framework that allows for comparability of environmental performance between products, ISO 14025 (2006) was introduced. This standard describes the procedures required to produce Type III environmental declarations (EPDs). This is based on the principle of developing product category rules (PCRs) which specify how the information from LCA is to be used to produce the EPD. A PCR will, for example, specify the declared unit and/or functional unit, what impact categories are

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to be reported and the units to be used for them. PCRs are developed by programme operators, who are responsible for disseminating and registering EPDs within their own programme, according to published procedures called general programme instructions. A range of EPD programmes has been initiated since the publication of ISO 14025 (2006) (Del Borghi 2013), with the result that there has been a correspondingly large number of PCRs published, which are not always harmonised with one another (Subramanian, Ingwersen, Hensler and Collie 2012). There are currently numbers of initiatives to harmonise different EPD programmes and their PCRs, but it is the introduction of standards which specify PCRs that is now rapidly leading to harmonisation.

Other standards have been issued that apply to the construction sector in order to ensure greater comparability of the environmental performance of products. ISO 21930 (2007) gave guidance on both PCR and EPD development, but this was recently replaced in Europe by EN 15804 (2012), which is a core PCR for building products and it is therefore considerably more detailed and prescriptive than ISO 14025 (2006) (ISO 21930 is currently being revised). The different life cycle stages are divided into modules in EN15804 (2012), modules A1–A3 cover the production stage (cradle to factory gate), 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), which might include the use of recycled material in a new product. These modules are listed in Table 1.

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.

The primary purpose of an EPD according to ISO 14025 (2006) 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 (2006) 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.

In order to make appropriate comparisons, it is necessary to have an agreed and standardised way of reporting data for a specific functional/declared unit. This has led to the introduction PCRs. The PCRs have been developed by different organisations which have set up EPD programmes (examples in Europe include the International EPD® system based in Sweden, the Norwegian EPD System (EPD Norge) and the Institut Bauen und Umwelt (IBU) in Germany). Since the introduction of ISO 14025 (2006), there has been a proliferation of EPD systems, with their own PCRs. ISO 14025 (2006) encourages the operators of EPD programmes to harmonise their methods and PCRs which 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 (2012) in the built environment).

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 reference 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.

One purpose of this study was to examine the published EPDs in the forest products sector and analyse the data on embodied carbon dioxide emissions and embodied energy contained therein. It was also decided to compare the results obtained with those published in the University of Bath Inventory of Carbon and Energy (ICE) database, first published in 2005 (Hammond and Jones 2005). This database is very widely used and referred to, since it is freely available. However, the information in the ICE database is now out of date and does not incorporate information from EPDs. Finally, a comparison of timber products was made with some common building materials using information in published EPDs. This comparison was made with the sequestered carbon storage excluded and included for the timber products.

Table 1 Different life cycle stages defined in EN 15804 (2012)

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

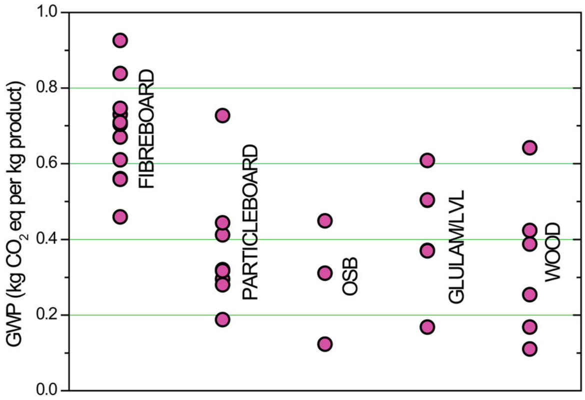
Experimental

At the time of compiling this review, the majority of published EPDs on wood-based composites have been published by the IBU e.V. in Germany, by Underwriters Laboratories in the USA, the Norwegian EPD Foundation and the International EPD System (Sweden). In making a comparison of the various published EPDs, it is necessary to understand the background and calculation methods used. The most recent European EPDs now follow the EN15804 (2012) core PCR. This divides up the life cycle of a product into different stages. For the purposes of this study, only life cycle stages A1 (raw material supply), A2 (transport) and A3 (manufacturing) have been compared (i.e. cradle to factory gate). This approach represents, potentially, the most accurate LCA data and does not involve assumptions regarding service life, maintenance and disposal, *etc*., which can increase the uncertainties when comparisons are made. For the purposes of this analysis, only GWP (embodied carbon dioxide emissions) and embodied energy associated with the manufacture of the products are considered, along with the quantity of atmospheric carbon dioxide sequestered in the product (embedded carbon) and the inherent energy of the product. Not all the published EPDs follow the EN15804 (2012) standard, *e.g*. those published outside of Europe and those published before 2012. Even where EN15804 (2012) is followed, there are anomalies in some cases.

Unfortunately, even such a relatively simple analysis of this type is confounded by a number of factors. The IBU EPDs (which were calculated by PE International, now called Thinkstep) include the sequestered carbon dioxide in the embodied GWP calculations. In many cases, this makes it impossible to determine the embodied GWP value associated with life cycle stages A1, A2 and A3. Where the sequestered carbon dioxide content is explicitly stated in the EPD, it then is possible to calculate the embodied CO_2 eq. emissions. The IBU EPDs also include module D (beyond building life cycle) where the assumption of incineration with energy recovery is applied. However, although carbon dioxide equivalent emissions are reported for module D, this includes the assumption that a proportion of the released energy is used to generate electricity, with avoided emissions from grid production as a consequence. Calculation of true emissions then requires knowledge of the grid production primary energy mix. However, it is possible to determine the sequestered carbon content in the different products by calculating the wood content on a dry mass basis, where the information is available in the EPD; the sequestered carbon content can then be calculated according to the methodology published in EN16449 (2014). Where the information was lacking in the case of some wood-based board products, a generic dry wood content of 85% of the mass of the product was assumed.

Results and discussion

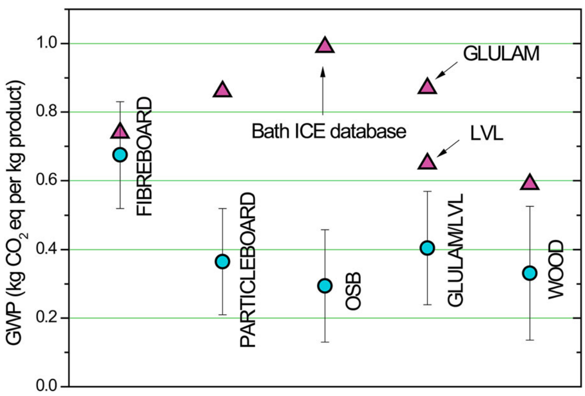
Figure 1 shows the global warming potential (GWP) (sometimes referred to as carbon footprint) for different wood products for 1 kg of the product. The results show considerable variability, although the GWP associated with fibreboard production is generally higher than the other product categories. The variability represents the differences in the grid energy mixes in various countries and other factors, especially the transportation associated with the production of the miscellaneous materials. This variation illustrates one of the difficulties associated with the evaluation of environmental impacts associated with the production of different materials; there is a range of values associated with a particular material and the absolute value is sensitive to the individual circumstances. For useful comparisons between diverse materials, it is necessary to analyse functional units (*e.g*. a wall element, a door, *etc*.) rather than the declared units (1 kg) given here, but it is the declared unit that



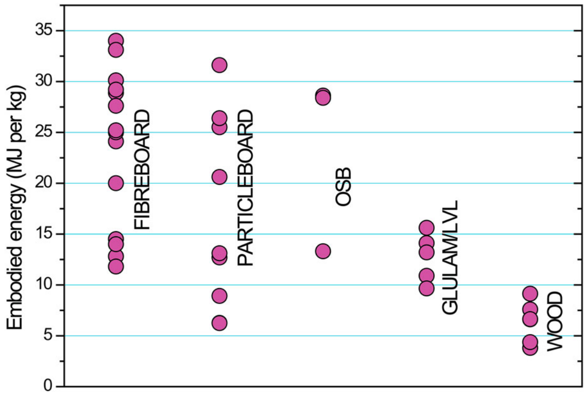
1 Comparison of embodied GWP emissions per kg of different timber products, where OSB is oriented strand board and LVL is laminated veneer lumber. Note that fibreboard includes medium density and high density fibreboard

forms the basis of all subsequent calculations. The information has been further processed to give the average value, range and standard deviation, and this data is compared with that reported in the Bath ICE database (version 2.0, 2011) in Fig. 2. The embodied carbon emissions data in the Bath ICE database are given in terms of a fossil and a biological component, but this has been combined to give a total for the purposes of this simple analysis. This comparison shows that the Bath ICE data give higher values of GWP for each product category, with the exception of the data for fibreboard. The Bath ICE database finds wide use in the construction sector due to its ready availability and it is instructive to see how that data compares with the more recent information contained in published EPDs. The Bath ICE database does not include seqestered atmospheric carbon in its treatment of timber products.

The embodied energy information contained within the published EPDs was also analysed. In some cases, this information is explicitly reported, but in the case of the EN 15804 (2012) compliant EPDs, it has been obtained by the summation of two impact categories (use of renewable primary energy excluding renewable primary energy resources used as raw materials, use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials). The data are presented



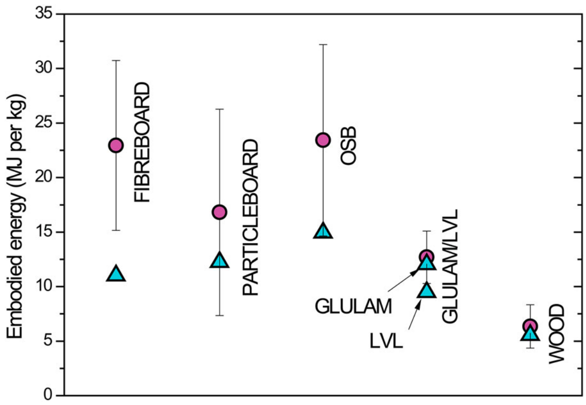
2 Comparison of the EPD data given in Fig. 1 as mean and standard deviation (circles) with GWP data obtained from the Bath ICE database (triangles)



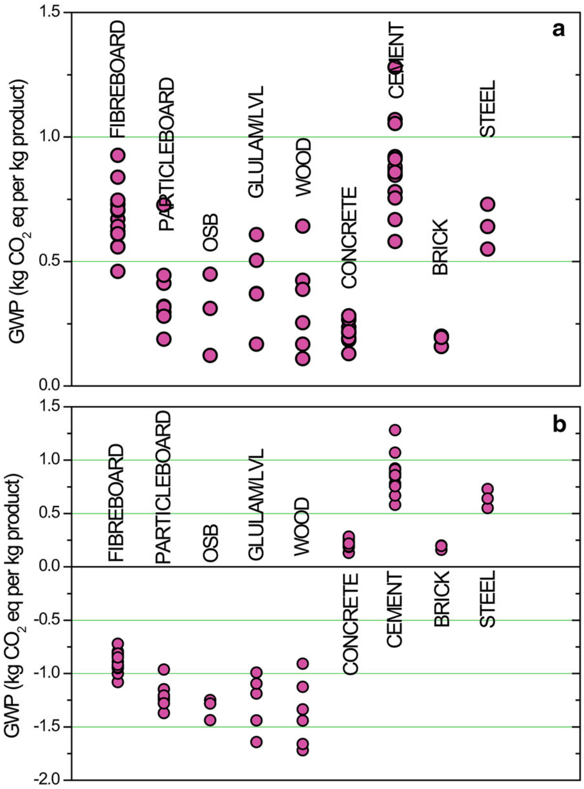
3 **Embodied energy data (in MJ per kg product) for different timber products obtained from published EPDs**

in Fig. 3. Although there still remains considerable scatter in the data, it is clear that in most cases, increased processing of the wood does result in a higher embodied energy. Once again, the data (average and standard deviations) are compared with that published (average embodied energy) in the ICE database (triangles), Fig. 4. The Bath ICE data for solid wood (softwood) are very close to the average of EPD data given here (also for softwood), and the Glulam embodied energy is also similar. However, in most cases the embodied energy data is lower than that presented in the current analysis, which seems somewhat anomalous given that the Bath ICE GWP values were generally higher. However, the 'best range' for embodied energy for high density fibreboard in the ICE database is between 15 and 35 MJ kg^{-1}, which is well within the range given here for fibreboard. The best range for particleboard is 4–15 MJ kg^{-1}, which is within the lower part of the distribution of values recorded here. Not enough data were available to quote an embodied energy range for MDF and OSB in the ICE database.

The GWP data obtained for timber products are compared with some common building materials in Fig. 5. This shows clearly that concrete and brick, both exhibit embodied GWP values in the lower part of the range of that associated with most timber products and that cement and steel both fall within the upper part of the range, or exceed the values for the higher embodied GWP timber materials. An important aspect of the use



4 **Comparison of the EPD data presented in Fig. 3 (as mean (circles) and standard deviation) with the average embodied energy data given in the Bath ICE database (triangles)**



5 ***a* Comparison of embodied GWP data for timber products with some common building materials taken from published EPDs, *b* same data, but including the sequestered atmospheric carbon in the timber products (as CO_2 equivalents)**

of timber products in the built environment is the ability to store atmospheric carbon dioxide over considerable periods of time. Provided that the timber is sourced from sustainably managed forests and used in long life products, it is legitimate to include the sequestered carbon in calculations of the GWP of the product. This has been done in Fig. 5*b*, where the sequestered carbon in the timber product (in CO_2 equivalents) is subtracted from the GWP. It is readily apparent that the sequestered carbon in the materials more than compensates for the embodied emissions associated with manufacture. Here lies one of the great advantages of using timber in construction. Irrespective of the timber product used and its associated embodied GWP emissions, the use of timber in construction always acts as a net carbon store.

Conclusions

A comparison of published EPD data for a range of timber products has been made with the widely quoted University of Bath ICE database. This has shown that the values of embodied GWP per kg of product quoted in the ICE database are considerably higher than the average values of the EPDs, except for the category fibreboard. The situation with respect to embodied energy is more complex. This study has shown that the ICE database does require updating with respect to timber products. Comparison has also been made with published EPDs of some other common building materials. The advantages from a GWP perspective of using timber as a construction material are clear when the sequestered carbon dioxide in the timber is taken into account.

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