An Application of the CEN/TC350 standards to an Energy and Carbon LCA of timber used in construction, and the effect of end-of-life scenarios.

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Abstract

The use of timber construction products and their environmental impacts is growing in Europe. This paper examines the LCA approach adopted in the European CEN/TC350 standards, which are expected to improve the comparability and availability of Environmental Product Declarations (EPDs). The embodied energy and carbon (EE and EC) of timber products is discussed quantitatively, with a case study of the Forte building illustrating the significance of End-of-Life (EoL) impacts. The relative importance of timber in the context of all construction materials is analysed using a new LCA tool, Butterfly. The tool calculates EE and EC at each life cycle stage, and results show that timber products are likely to account for the bulk of the EoL impacts for a typical UK domestic building.

Keywords: Embodied Carbon, Life Cycle Assessment, Timber, Built Environment

1. Timber construction and Life Cycle Assessment (LCA) in Europe

The use of timber in construction in Europe has been growing over the last decade, and is predicted to increase, by 80% in the UK alone between 2012 and 2016[1], outperforming other segments of construction industry. This growth can be attributed to increasing market share of traditional timber frames, but also the introduction of new innovative timber products and techniques, such as cross-laminated timber (CLT). Evidence of the environmental benefits of timber products often includes their ‘embodied energy’ (EE) and ‘embodied carbon’ (EC), defined as the energy consumed and global warming potential (CO2e) of emissions due to the use of that product.

In Europe LCA data for products is communicated in a particular form known as an Environmental Product Declaration (EPD). EPDs have been produced for construction products since the 1990s in many European countries, in accordance with various generic ISO standards[2,3]. There are many aspects of the LCA that are not covered in detail in these standards, leading to each EPD system making different assumptions on fundamental issues such as scope and system boundaries, and so an EPD for the same product may show different data in different countries.

Concerned that these different EPD schemes would represent a barrier to trade across the continent, the EU introduced a suite of standards, CEN/TC350, that would provide a ‘horizontal’ (i.e. applicable to all construction products and building types) approach to the measurement of embodied and operational environmental impacts of products and buildings across the entire life cycle. The first standards in this suite were published in 2010, and in February 2012 EN15804[4] , the core rules for construction product EPDs, was published, paving the way for manufacturers of construction products in Europe to undertake only one LCA study to obtain a Europe-wide compliant EPD. The Calculation Methods Standard, EN 15978[5], providing the rules for evaluating and reporting the whole life impact of a building, was published in November 2011. This is an important development for policy in the UK: in 2010 the UK Government’s chief construction advisor published an influential report on Low Carbon Construction[6], stating that “CEN-TC350...should be the basis of measuring embodied carbon in products and projects”.

2. Summary of the CEN/TC350 approach

The CEN/TC350 approach to LCA is a modular process analysis, as shown in Fig. 1. Of the environmental indicators that are required to be included in any assessment the ones of relevance to this paper are Global Warming Potential (GWP), in units of kg CO_2eq, and Primary Energy Use, both renewable and non-renewable, in units of MJ (net calorific value).

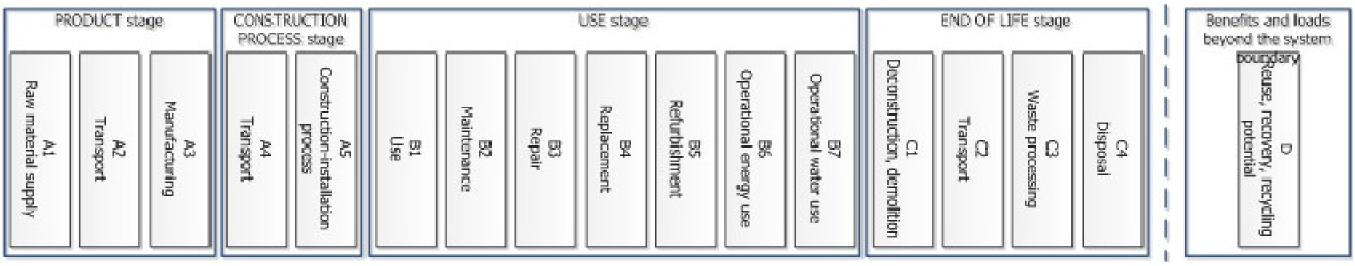

Figure 1: The modules of the CEN/TC350 process LCA approach

A1-A3 are ‘cradle-to-gate’ impacts, A4 is the impact of transportation of the product to its site and A5 is the impact from the construction processes associated with the product. B1 relates to the use of the product (which is not relevant to EE and EC). B2-B5 are the impacts from any maintenance, repair, replacement and refurbishment for the product. C1-4 cover impacts associated with the removal of the product from the building at end of life, right through waste processing until it reaches an ‘end-of-waste’ state, as defined in the standards. Module D is any benefits that arise, usually from recycling or energy recovery at end of life, which may be attributed to the product, but occur outside the system boundary.

For EPDs produced in accordance with CEN/TC350 standards only modules A1-3 are mandatory, essentially giving a ‘cradle to gate’ analysis. In order to produce a complete life cycle analysis the remaining modules are required, but many EPDs will not include them. The methodology is a pure ‘process’ approach, with no consideration for ‘input-output’ methodology. This may result in ‘truncation’ of results, because only including the energy and carbon impacts of the direct manufacturing processes associated with products will significantly under-represent the impacts of that sector of industry as a whole[7].

The inclusion of Module D means that a so-called ‘0:100’ or ‘substitution’ recycling methodology is used, with benefits of recyclability included in the analysis although they will be taken outside the boundary of the system being considered (a particular construction product or building). There is a requirement that Module D results must be reported separately from results of the other modules, recognising the fact that these benefits only have a *potential* of being realised. Given that the design life of buildings and therefore most structural building products is around 60 years it is difficult to say with any certainty what recycling practices will be commonplace at the end-of-life of a product being manufactured today.

3. Special Features of Energy and Carbon LCA studies of Timber

Trees remove and store around 1.8kg CO_2/kg wood from the atmosphere during growth. Wood densities vary with tree species and moisture content, but wood used in construction is typically around 500kg/m^3 so the CO_2 sequestered is around 900kg CO_2/m^3[8,9].The energy content of wood is normally around 17MJ/kg[8,9], also dependent on tree species and moisture content. It is important to know whether the forest from which the timber is sourced is sustainably managed, i.e. if the area of forest is constant or increasing. If so the manufacture of the timber products has resulted in an overall increase in total volume of biomass, therefore a net reduction of CO_2 from the atmosphere. If the timber is sourced from unsustainable sources, resulting in net deforestation, all that has been achieved is the movement of one carbon store (a tree) to another (the timber product), and no net removal of CO_2 from the atmosphere is achieved.

A consensus is yet to be reached on how carbon sequestration in timber products is dealt with in LCAs, and it is not explicitly addressed in the CEN/TC350 standards. There are numerous publications on the subject[8,10-16]. Most LCA studies of timber products conclude that sequestration of carbon should be included, but that care is required in the consideration of the destination of that carbon when the product reaches the End-of-Life stage (EoL). Three potential scenarios are addressed here: recycling, incineration and disposal in landfill.

- ***Recycling***

When a timber product is recycled into a new timber product the carbon stored in the timber remains in the timber and is not returned to the atmosphere in the form of CO_2. This is extremely beneficial, as it means the carbon 'credit' taken in sequestration remains intact at the end of life. An energy credit could be taken into account for potential savings in manufacturing from recycled materials over virgin materials but, given the level of detailed analysis this would require, this has not been included in this study.

- ***Incineration***

When timber is incinerated, assuming full combustion, an equal amount of carbon is released back into the atmosphere (as CO_2) as was originally sequestered in the timber: approximately 1.8kg CO_2/kg. The feedstock energy stored in the timber (17MJ/kg) is also released and may be recovered; if this is the case, an energy credit can be taken here. There is also a case for taking a carbon credit if the energy is used in a national grid system with a dominant fossil fuel source. The energy recovered from the timber is therefore reducing the amount of fossil fuel being consumed and the credit is equal to the marginal (offset) emissions that would otherwise have been made. For the purposes of quantifying these impacts in this study, it is assumed energy is converted into electricity at an efficiency of 20%[8][17], therefore 1kg of wood with a calorific value of 17MJ/kg will produce 1x17x0.2=3.4MJ. The CO_2 emissions from the grid electricity that is being offset is assumed to be 0.59kg CO_2/kWh (0.16kg CO_2/MJ) electricity (the UK electricity carbon coefficient)[18]. So recovering energy from 1kg of timber avoids emissions of 0.16x3.4=0.6kg CO_2.

- ***Landfill***

As timber decomposes in landfill the carbon stored in it is gradually released back into the atmosphere, in the form of CO_2 or methane depending on whether the decomposition is aerobic or anaerobic. Methane has a GWP 25 times that of CO_2 [19], but the fear of significant amounts of carbon in timber decomposing into methane when it is landfilled has been shown to be unfounded[8,20,21] and has lead to overestimates of greenhouse gas emissions from timber in landfill. The proportion of carbon in timber that returns to the atmosphere varies depending on moisture, temperature, landfill gas management procedures and other waste products in the landfill. This paper conservatively assumes 20% of the carbon decomposes, 60% to methane and 40% to CO_2 and none of the landfill gas is recovered. The latter is particularly important as high landfill gas recovery rates (around 50-70%) can significantly reduce the carbon impact of landfilling timber[24]. As landfill site management practices vary around the world and cannot be guaranteed, the analyses in this paper prudently assume the worst case. The approximate carbon impact of this scenario is shown in Table 1:

Quantity Description	**Kg**
Dry Mass of landfilled timber:	1
Mass of carbon in landfilled timber (50% of timber by mass):	0.5
Mass of carbon that will decompose in landfill (20% of carbon by mass):	0.1
Mass of carbon that decomposes to Methane (60% of decomposed carbon):	0.06
Mass of carbon that decomposes to CO_2 (40% of decomposed carbon):	0.04
Mass of Methane emissions (mass of decomposed carbon to methane x (12+4)/12):	0.08
Mass of CO_2 emissions (mass of decomposed carbon to CO_2 x (12+16x2)/12):	0.15
CO_2 equivalent of Methane emissions (GWP =25)	2.0
CO_2 equivalent of CO_2 emissions (GWP =1)	0.15
TOTAL CO_2 equivalent emissions	**2.15**

Table 1: Calculation of the end-of-life carbon impact of landfilling timber

The energy and carbon impacts for each EoL scenario are collated in Table 2, together with the energy and carbon impacts for the other key stages in a timber product. These will of course vary significantly between different products and so the figures shown are included only to allow an 'order of magnitude' comparison. Impacts of transportation and construction have also been omitted as they are typically, but not always, negligible (see section 3):

		Energy impact (MJ/kg)	**Total over life cycle (S+M+EoL):**
S Sequestration		0	
M Manufacture		10[8]	
EoL End of life	- recycling	0	10
	- incineration, no energy recovery	0	10
	- incineration, with energy recovery	-3.4	6.6
	- landfill with no landfill gas recovery	0	10
		Carbon impact (kg CO_2/kg)	**Total over life cycle (S+M+EoL):**
S Sequestration		-1.8	
M Manufacture		0.7[8]	
EoL End of life	- recycling	0	-1.1
	- incineration, no energy recovery	1.8	0.7
	- incineration, with energy recovery	1.3	0.2
	- landfill with no landfill gas recovery	2.15	1.05

Table 2: Life cycle energy and carbon impacts of timber products for different EoL scenarios

4. Case study: Significance of EoL on a timber building carbon LCA

The ten storey Forte building in Melbourne is the world's tallest timber residential building, containing 1077m^3 of CLT panels, supplied and manufactured by KLH, an Austrian CLT company. EC data for the panels was taken from the EPD for KLH CLT panels[22]. The carbon impacts of transporting the panels was also considered, assuming the panels were freighted by road and sea. The EoL scenario presented in the KLH EPD assumes 100% incineration at end of life with energy recovery (heat and electricity) in a plant with 90% efficiency, offsetting emissions from fossil fuels (EU average emissions used). The approximate carbon impacts of this and three other EoL scenarios are show in Table 3:

Life cycle stage	**Total carbon impact of CLT, tonnes CO_2e**	**Notes**
Sequestration	-913	-1.8kg CO_2/kg [22]
Manufacture	71	0.135kg CO_2e/kg [22]
Transportation	375	CO_2e coefficients from DEFRA/DECC guidelines 2011[18]
End of Life - EPD scenario	462	Total emissions of 811t CO_2e, and credit of -349t CO_2e for offsetting fossil emissions.
End of Life – 100% Recycled	0	Coefficients as discussed in section 3.
End of Life – 100% Incinerated, no energy recovery	913	Coefficients as discussed in section 3.
End-of-Life – 100% landfilled, no landfill gas recovery	1090	Coefficients as discussed in section 3.

Table 3: Carbon impacts for life cycles stages and four EoL scenarios, Forte Building

The approximate total life cycle EC for each EoL scenario is shown in Figure 2. The carbon impact of transporting the timber is significant in this example. If the timber had been sourced from New Zealand and shipped from Nelson, the transportation impacts would have been reduced from 375t CO_2e to 26t CO_2e. (Note that an allowance for the impact due to transportation of waste products has been not included in any of the EoL scenarios).

It can be seen that the end of life scenario makes a significant difference to the total EC of the building, ranging from -467t CO_2e to +623t CO_2e for the building depending on which scenario is taken. This would imply that statements about the life cycle carbon impact of the building cannot be justified until the end of life scenario is known.

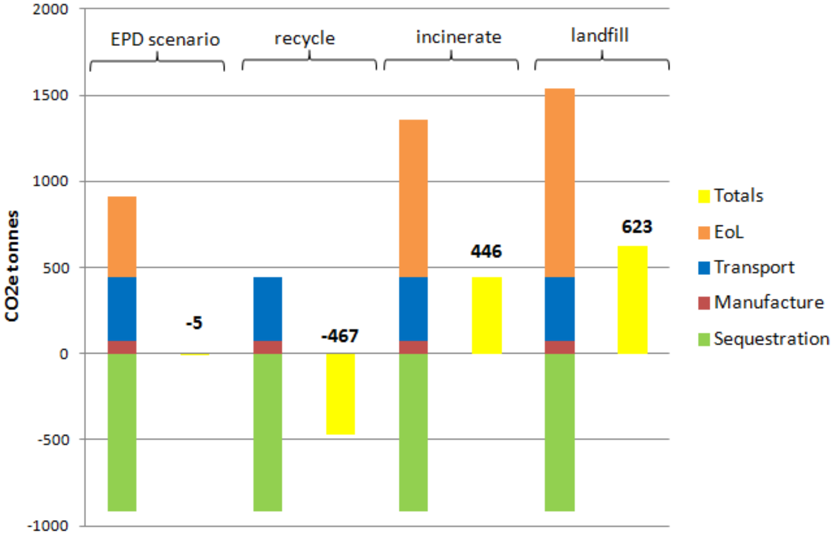

Figure 2: Life cycle EC for 4 EoL scenarios, Forte Building

5. Case Study: EE and EC of timber in a UK domestic building

The Forte building case study only considers the life cycle carbon impacts of the structural timber in the building, omitting the impacts from all other components in the building, including foundations, finishes and cladding. The authors have developed the EE and EC part of a whole life cost, energy and carbon tool called ‘Butterfly’. The tool is applicable to domestic UK buildings, and the EE and EC is broken down into life cycle phases, equivalent to the CEN/TC350 modules.

The assumed EoL scenario for timber after demolition is 50% incineration (with energy recovery), and 50% landfill disposal. This is a very conservative approach since landfilling rates of timber in the UK are declining and expected to continue to do so[23] and recycling of timber is also fairly commonplace. However, since the tool also includes the carbon credits for sequestration in timber, it was considered prudent to assume a ‘worst case scenario’ for EoL impacts.

Table 4 shows the proportion of the impact attributable to timber products for the early life cycle stages and for alternative EoL scenarios for an energy and carbon LCA of a traditional UK masonry domestic building. Timber construction products account for the bulk of the ‘positive’ EoL EC (modules C1-C4) and benefits outside the system boundary, or ‘negative’ EoL EC (module D). It can be seen that even in traditional masonry construction, the timber present in the building accounts for a significant proportion of the end-of-life carbon impacts.

		% of impact attributable to timber products				
Modules A&B	Energy	7%				
	Carbon	4%				
EoL Scenario		*Butterfly base case*	*100% recycled*	*100% incinerated, no energy recovery*	*100% incinerated, with energy recovery*	*100% landfilled, no landfill gas recovery*
Module C1-C4	Energy	4%	4%	4%	4%	4%
	Carbon	84%	7%	88%	88%	91%
Module D	Energy	7%	0%	0%	14%	0%
	Carbon	79%	77%	77%	81%	77%

Table 4 – EE and EC of timber as a proportion of the total building’s impact at each life cycle stage

6. Conclusions

Energy and Carbon studies of timber construction products need to carefully consider the possible and likely EoL scenarios, as they have a significant impact on the total life cycle impacts. This also applies when doing an energy and Carbon LCA study of a whole building, even if it is not a predominantly ‘timber’ building. The use of heavyweight timber building systems, such as CLT, has the potential to have a negative carbon impact over its lifecycle, if a recycle or incinerate with energy recovery EoL scenario can be guaranteed.

It is hoped that the adoption of CEN/TC350 standards, with their specific rules about LCA of construction products, will bring about an increase in availability of EPDs for timber products.

References:

[1] Timber frame construction market research and analysis, MTW research, April 2012

[2] ISO 14040:2006 Environmental management -- Life cycle assessment -- Principles and framework, International Organization for Standardization

[3] ISO 14044:2006 Environmental management -- Life cycle assessment -- Requirements and guidelines, International Organization for Standardization

[4] BS EN 15804:2012 Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products

[5] BS EN 15978: 2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method

[6] Low Carbon Construction IGT Final Report, Autumn 2010, HM Government BIS

[7] Validation of a hybrid life cycle inventory method, Crawford (2008), Journal of Environmental Management, vol 88

[8] Embodied through-life Carbon dioxide equivalent assessment for timber products, Weight (2011), ICE Energy vol 164

[9] Ragland KW, Aerts DJ, Baker AJ (1991) Properties of wood for combustion analysis, Bioresource Technology vol 37

[10] Embodied Carbon: The Inventory of Carbon and Energy, Hammond and Jones (2011), BSRIA/University of Bath

[11] PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services, BSI

[12] Characterizing the importance of Carbon stored in wood products, Lippke et al (2010), Wood and Fiber Science, vol 42

[13] Life cycle primary energy use and carbon emission of an eight storey wood framed apartment building, Gustavsson et al (2009), Energy and Buildings vol 42

[14] Tackle climate change, use wood, Beyer et al (2011), CEI-Bois report

[15] Comparing Life cycle carbon and energy impacts for biofuel, wood product and forest management alternatives, Lippke et al, 2012 Forest Products Journal, vol 62

[16] Carbon sequestration by timber buildings, P Sadler, D Robson (2012), ASBP report

[17] Carbon balances and energy impacts of the management of UK waste streams, Fisher et al (2006), DEFRA report

[18] Guidelines to DEFRA/DECC’s GHG conversion factors for company reporting, v1.2 August 2011

[19] IPCC 4th assessment report, 2.10.2 Direct Global Warming Potentials, table 2.14

[20] The decomposition of wood products in Landfills in Sydney Australia, Ximenes et al (2008), Waste Management, vol 28

[21] The decomposition of forest products in landfills, Micales and Skog (1997), International Biodeterioration and Biodegredation, vol 39

[22] EPD KLH Solid Timber Panels, declaration number EPD-KLH-2012111-E, Institute Bauen und Umwelt (IBU)

[23] Realising the value of recovered wood, WRAP Market Situation report 2011

[24] Quantifying the greenhouse benefits of the use of wood products in two popular house designs in Sydney, Australia, Ximenes, & Grant (2013), Int J Life Cycle Assessment, vol 18