ARUP

Buildings & Infrastructure Priority Actions for Sustainability

Embodied Carbon

Timber

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This document is a snapshot in time of industry research, opinion, and knowledge. The information is subject to change as industry progresses and new information comes to light. This document is to be periodically reviewed and any comments or suggestions are welcomed via jo.spencer@arup.com and the BIPAS team. BIPAS is a multi-disciplinary group of engineers within Arup, funded via Arup's internal investment programme. We carry out research and create resources relating to sustainability, primarily for use within Arup but shared externally when it is appropriate. Our objective is to address those areas that engineers engage with on a daily basis, to enable them to address sustainability in an informed and effective manner.

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Introduction

With the building and construction industry accounting for 40% of annual CO_2 emissions [1], decarbonising the buildings sector is imperative. In the search for lower carbon materials, biogenic materials are gaining popularity due to their potential for reduced global warming potential (GWP), and capability for regrowth to provide a renewable construction resource. It is estimated that global demand for wood products will quadruple by 2050 [2].

The carbon assessment of timber is highly sensitive to sourcing, so it is important that we collectively align our understanding of the lifecycle stages. Each stage from raw material extraction through to maintenance and disposal can require the use of fossil fuels, and therefore a detailed assessment is required. Timber should be treated as a scarce resource, and designed with this in mind. This document aims to set out the factors that contribute to the emission of carbon through the whole life cycle of the following timber products:

- Softwood: Used in the construction of internal features such as windows, door frames, joists and roof trusses typically of domestic scale buildings
- Glued-laminated timber (Glulam): Used for load bearing elements such as rafters, beams, slabs and columns
- Cross-laminated timber (CLT): Used for surfaces and build ups such as walls and floors.

Carbon definitions

It is important to distinguish between the different types of carbon referred to when discussing timber products; the following definitions are from EN 15804:

Fossil carbon: CO_2 released from permanent stores, such as fossil fuels (combustion) or limestone (calcination).

Biogenic carbon: Relates to the natural carbon cycle. It includes carbon stored in bio-based materials, including plants, which is sequestered through photosynthesis and released through combustion or decomposition as part of a carbon cycle.

Timber in context

Whilst it is widely perceived that bio-based materials have the potential to be more sustainable than traditional materials, the assessment of biogenic benefits is complicated and there is less clarity on how to incorporate this into Life Cycle Assessments (LCAs). The main discrepancy in LCAs is relating to the treatment of biogenic carbon stored in the materials, and the methodology for tracking the storage and flows of biogenic carbon across the lifecycle stages, known as sequestration.

It is important for material comparisons to be made based on equivalent performance. Biogenic materials are combustible, so careful holistic design is needed to achieve fire-safety performance and any protection measures should be included in the assessment. Timber structures are light weight, so will also need careful consideration of acoustic and dynamic design. The additional mass associated with fire protection, may also benefit acoustic and dynamic performance, if the design is considered holistically.

Using less material as an industry is **fundamental** to reducing emissions. For one project, timber might provide a lower carbon alternative to other materials. For another, where it is not an appropriate structural material, or where procuring sustainably managed timber is difficult, or where it is used inefficiently, it can become a higher carbon option. Industry consensus is hard to reach at the best of times, and timber is an area which is evolving particularly quickly. How sequestration is accounted for is critical if we are to avoid encouraging inefficient use of material, but consensus on how that should be done has not yet been reached. This paper aims to provide the reader with information on the status of the industry and best practice, so that they can understand the impact of their design choices and avoid greenwashing.

Lifecycle

The stages referred to in this document are compliant with the life cycle assessment referenced in ISO 14040, whereby Stage A is ‘up-front’, Stage B is ‘in-use’, Stage C is ‘end-of-life’ and Stage D is ‘beyond life-cycle’. Figure 1 shows how a timber product’s lifecycle (in this case CLT) fits into the lifecycle assessment Stage A and the approximate proportion of fossil carbon associated with each, based on European manufacture and transport from Austria to the UK.

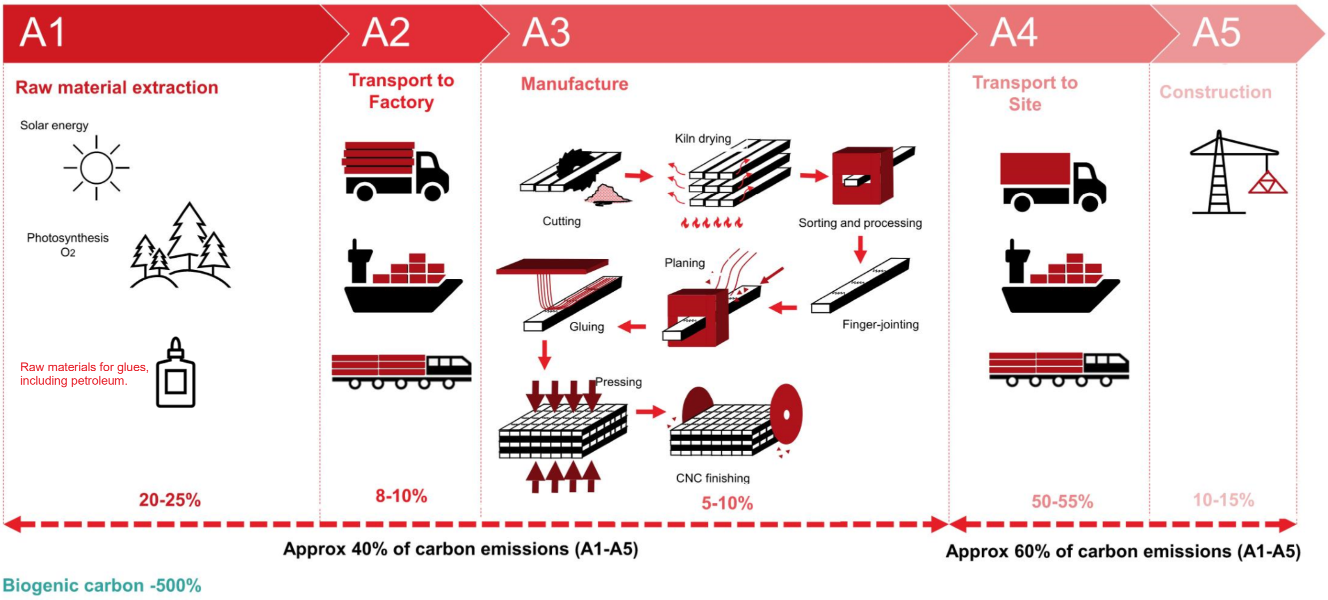


Figure 1
CLT Product Lifecycle, and approximate percentage of A1-A5 carbon each stage accounts for, based on multiple resources including EPDs and various data extracts. Data is based on European manufacture and transport from Austria to the UK.

Stage A

A1 – Raw material extraction

Module A1 includes carbon emissions associated with raw material extraction and processing, and the contribution of secondary material input (e.g. the recycling process of timber). It typically accounts for 20-25% of the A1-A5 fossil carbon emissions of a timber product, as shown in Figure 1.

Wood

The wood used in engineered timber products comes from trees grown in forests worldwide. Re-growing felled trees and maintaining ecological systems is essential to mitigate climate change. Understanding how our forests can be maintained and restored to become sustainable sources of wood requires understanding of the importance of biodiversity, and intricate knowledge on the wider carbon and ecosystem cycles [4].

Biogenic carbon cycle

Trees convert carbon dioxide, sunlight, water, and nutrients into food that allows growth; subsequently, oxygen is released into the environment. As trees remove carbon dioxide from the atmosphere through photosynthesis, they store approximately one tonne of CO_2 per cubic metre of wood; carbon that is stored in this form is called 'biogenic carbon' [5]. Over time, as trees die, they are consumed by microbes, naturally decomposing. Some carbon is stored into the soil and the rest is released as carbon dioxide back into the atmosphere [6]. The biogenic carbon cycles take place over a period that can span between months and decades. Figure 2 illustrates the difference between biogenic and fossil carbon and how this carbon cycle relates to the timber stages, starting with the raw material extraction (A1).

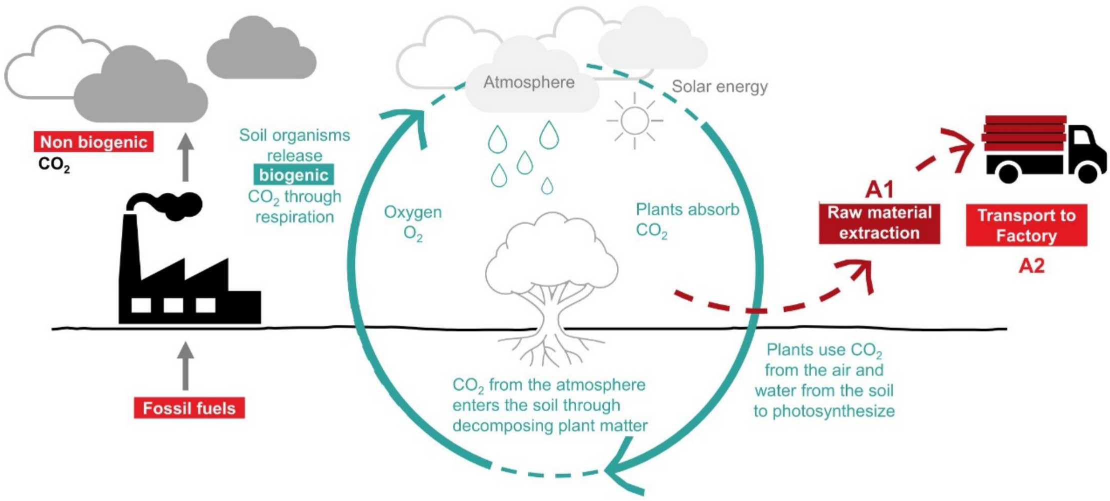


Figure 2
Biogenic and non-biogenic (fossil) carbon within the raw material extraction stage.

Forestry and harvesting

On a global scale, forests are key in managing and maintaining the earth's carbon balance as they act as one of the world's largest carbon sinks by storing carbon in soil and trees long-term [8]. If managed correctly, harvesting improves the carbon balance of forests in the long run [9]. When timber is sourced from a well-managed, sustainable forest, the benefits of sequestration can be considered in our carbon calculations [10]. Land use and the associated carbon needs more understanding, as there are wider impacts of cutting down a tree. According to EN 16485, if timber is sustainably sourced, then land use/land use change impacts do not need to be included in the assessment - the overall increase in carbon balance cannot be accounted for, and this is larger than any short term emission after harvest. The appropriate selection of tree species should be considered.

There are two main global certification schemes (FSC and PEFC) which aim to ensure supplies are from sustainably managed forests [11]. Figure 3 shows the certification scheme logos, which should always be sought in the supply of structural timber.

Figure 3

FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification) logos.

In theory, FSC regulation manages demand, because new growth volumes must be more than the felling volume. The timber industry is only able to increase gradually, as market-availability limits the speed of uptake. However, forest growth must be heavily invested in *now* both as a form of carbon offset, and to create wood stocks for the next generation.

Being conscious about where timber is harvested from plays a significant role in creating carbon stores and lowering greenhouse gas emissions. The ability to protect and restore forests lies within the biodiversity of these ecosystems [4], but also in their sustainable management as natural resources.

If there is a dramatic increase in the demand for timber over the next decade, it may not be guaranteed that the European market for sustainably managed timber can keep up [12]. Non-certified timber may start to enter Europe to meet demand, potentially leading to sub-optimal procurement. The prevailing international opinion is to stimulate tighter forestry regulation and guardianship by promoting the value of wood products and environmental services. We should also really pay attention to improving the resilience of forests to climate change including higher temperatures, lower humidity, and more frequent insect outbreaks. The timber harvest time is very important for successful forest re-growth, biodiversity, reducing the energy for timber drying, and improving timber material quality. It should be harvested when trees have very low moisture, and not during growing season, such as in summer. Some certification schemes do not currently consider this.

Availability of sustainably sourced timber should be assessed on a project-by-project basis. Faster growing plants, such as bamboo, could be considered for structural purposes to manage demand levels.

Biodiversity

Billions of micro-organisms within the soil regulate the biodiversity underground. They provide the nutrients to allow trees to grow and play a key role in sequestering carbon within the soil. The replenishment of these microorganisms globally could facilitate the restoration and increased productivity of new forests; however, they rely on the diversity of their ecosystems to thrive. A loss of biodiversity, including the growth of mono-species forests, reduces the soil's capacity to act as a carbon store and leads to further carbon dioxide being emitted into the atmosphere. The UK forestry commission is now moving away from monoculture plantations. Biodiversity is a complex subject that must not be underestimated. However, the restoration and maintenance of our diverse ecological systems is key to fighting climate change [4].

Adhesives

The development of timber products using adhesive technologies enables the production of boards, panels and elements that are not constrained by the size dimensions of sawn timber. It has enabled the production of larger structural components that can then create larger buildings. The adhesives used are typically made from oil which is a finite resource, and energy intensive to extract. Figure 4 shows the inputs and outputs in the production of an adhesive. Based on data from a selection of Environmental Product Declarations the main types of adhesives used in Glulam and CLT are identified in Figure 5. Polyurethane is the most used in CLT, and Melamine-Urea-Formaldehyde (MUF) in Glulam. MUF, Melamine Formaldehyde (MF), Phenol Formaldehyde (PF), Emulsion Polymer Isocyanate (EPI) and Polyurethane Emulsion Polymer (PEP) are two-part thermosetting adhesives, whereas Polyurethane (PUR) and Polyvinyl Acetate (PVAc) are single pack adhesives which will soften again with increasing temperature. This is particularly relevant when considering that timber exposed to a fire will form an insulative char, slowing the burn-rate of the timber. The char layer will gradually work through the Glulam/CLT element during fire exposure. When the fire nears the glue lines of the laminated timber, the performance of the glue can lead to delamination, thus influencing how the timber will be able to withstand the fire.

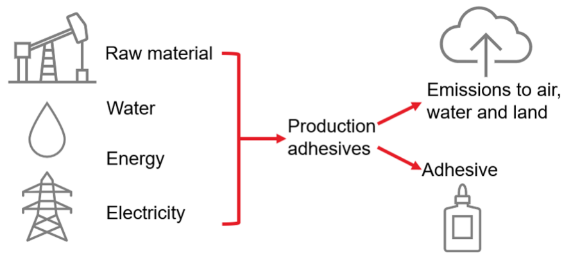


Figure 4

Inputs and outputs to the production of adhesives.

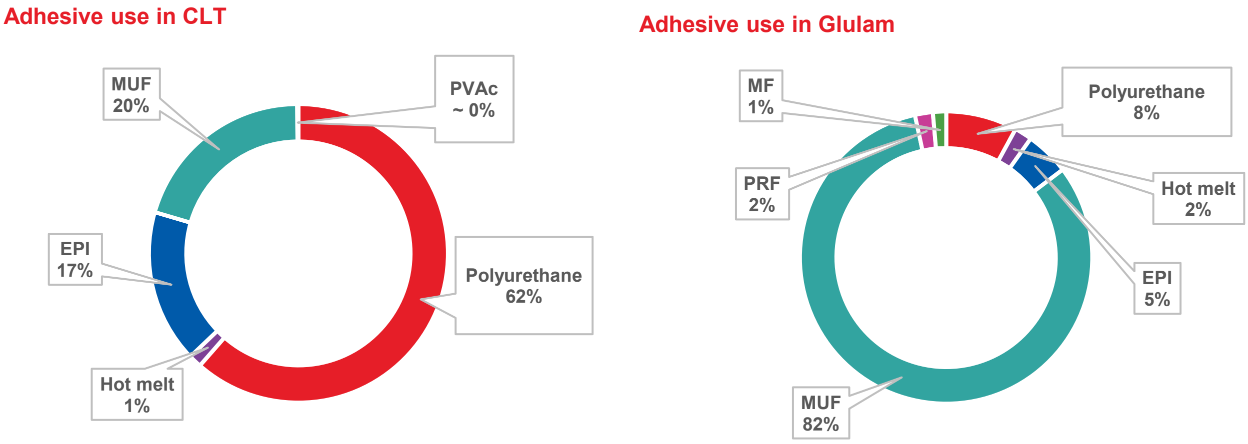


Figure 5

Data on adhesive used in CLT and Glulam based on data provided in product EPDs of European manufacturers.

CLT and Glulam typically contain 1-2% and 1.5-2.5% by volume of adhesive respectively. Data on the GWP of these materials is not widely available. Data shown in Figure 6 shows a collection of embodied carbon factors for a number of adhesives, obtained from a variety of sources, which means they are not readily comparable. Adhesives contribute significantly to the GWP of these products. Products such as dowel laminated timber does not include any glues, which can provide an advantage in this respect.

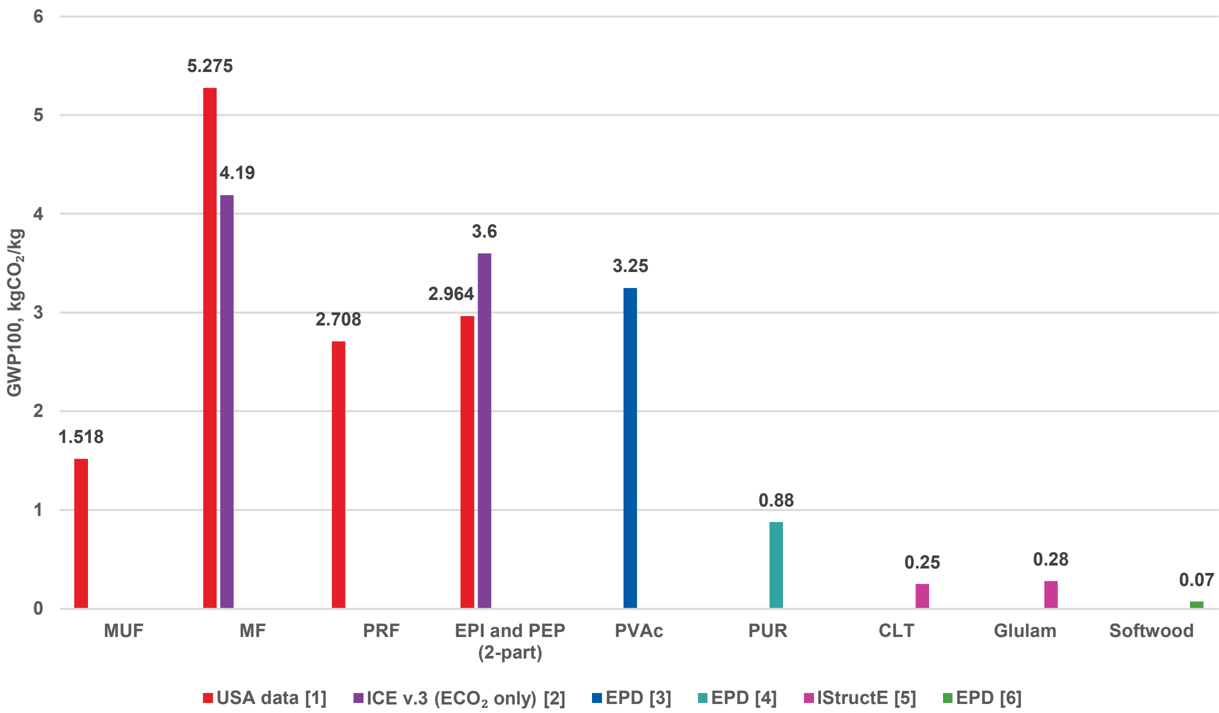


Figure 6
Embodied carbon/GWP of adhesives and CLT, glulam and softwood for comparison. NB the ICE data is CO_2 only.
References: [1] USA Data 920 ICE v.3 [3] EPD [4] EPD [5] IStructE [6] EPD.

Adhesives made with PRF, MUF or MF all contain added formaldehyde which is a known toxic carcinogen. Production methods have greatly reduced formaldehyde emissions and most bonded timber products are classified E1, which is the lowest European classification for formaldehyde emissions. The emissions can be reduced further by selecting no added formaldehyde products or identifying ones with third party certification and demonstrating lower emissions. However this can affect the performance (as formaldehyde-based adhesives are typically the most durable and moisture and heat resistant). Alternatives include bio-based adhesives, or dowels or brettstapel, avoiding the use of glues altogether.

CLT, Glulam, board products and softwoods can generally be recycled, however surface treatments (paints and varnishes) and other chemical treatments for preservation or fire performance may negatively impact the recyclability of timber. It is most advantageous to reuse them. Recycling is downcycling to wood chip and they can only be used in particleboard (and possibly OSB).

A2 & A4 – Transport of materials to the factory and finished products to the site

Module A2 includes the carbon emissions associated with the transport to the factory, and module A4 includes the carbon of the transport from the factory to the construction site. A2 typically accounts for 8-10% of the A1-A5 emissions, and A4 typically accounts for 50-55%, but can be highly variable.

If the timber has PEFC and FSC certification, the raw materials can be tracked back to their original locations. [13] Understanding the timber origin will significantly impact the A4 embodied carbon.

The type of transport mode used to move raw materials, kiln-dried timber, and finished products, will depend on the location of forests, sawmills, processing facilities, and the construction site. Raw material is generally transported from forests to sawmill via road, rail, or a combination of both. Kiln-dried timber is then transported to processing facilities, the locations of which can vary significantly. From the processing facility, the finished products are either transported to the construction site directly or to storage facilities. Figure 7 shows the carbon produced for each mode of transport used to transport timber products in the A2 and A4 stages.

Figure 7
Carbon associated with the transportation of timber.

At design stage, the location of the raw wood and sawmills is unknown; softwood glulam and CLT complying with European standards is only currently manufactured in Europe, which limits the maximum likely transport distance. Table 1 can be used to help estimate the carbon associated with transporting material depending on the distance. In Europe, saw-mills tend to be in or near the source forests and also fairly close to CLT/Glulam factories, hence the distance from sawmill to site is likely to be "local" or "regional". For a UK project, it would be reasonable to assume a combination of transport by road and sea from Austria as an initial approximation.

Table 1
Default A4 transport carbon emissions if specific locations are unknown [5].

Location of Mill compared to the site	Carbon Emissions $kgCO_2e/kg$	Assumption
Local <50km	0.005	Transported 50km by road
National <300km	0.032	Transported 300km by road
Regional <1500km	0.161	Transported 1500km by road
Global >1500km	0.183	Transported mostly (10,000 km) by sea and then 200km by road

Embodied carbon that is released through burning fossil fuels for transport can be significant when projects are relatively far from productive forests. The electrification of railways, and development of hydrogen powered heavy goods vehicles (HGVs) are two changes which will hopefully see transport emissions fall over the coming years. In theory, carbon emissions associated with transport could drop to zero.

Sourcing and production

In 2020, the global production capacity of CLT comprised of 48% in Europe, 43% in North America, 6% in Oceania and 3% in Asia. The vast majority of European production is in Austria, Czech Republic, Germany, Italy and Switzerland [14]. Figure 8 and Figure 9 show the largest CLT manufacturers within Europe and North America.

Figure 8
CLT Manufacturers Europe (various sources).

Figure 9
CLT Manufacturers North America (various sources).

Glulam products are manufactured in more locations as it is a more mature market, than CLT. This potentially enables a more local supply than CLT, although manufacturing is inevitably concentrated in the highly forested areas of the world, which are remote from the large population centres where most building takes place. In addition, in some regions such as Australia, demand is high, and a large proportion of CLT is imported, often from central Europe. In other regions, it will often be necessary to import because the local climate cannot support the workable softwood species that are most suitable for Glulam and CLT. The European Green Deal will further incentivise capacity increase of CLT and Glulam production.

International timber trade

Structural sawn and engineered timber, should be sourced locally wherever possible to reduce the carbon emissions associated with transport. However, this is not always possible or the most sustainable option overall. International trade of timber is often regional, such as USA-Canada trading.

European timber is exported throughout the world. Japan for example, the fourth largest importer of timber products, has an average import distance of 8,503km. This is much further than the UK, the second largest importer, which imports European timber predominantly, and has an average import distance of 1,818km. Tables 2 and 3 show the top export and import countries of timber globally.

Table 2
Exporters of sawn timber.

Country (Listed by largest exporters)	Average Distance of exports (km)	Top export countries (2021 – ITC)
Canada	2,540	USA (84%), Japan (7%), China (3%)
Sweden	2,758	UK (25%), Norway (10%), Netherlands (8%), Japan (8%), Denmark (7%)
Germany	3,947	USA (24%), Netherlands (9%), France (9%), Austria (11%), UK (8%)
USA	6,991	China (27%), Canada (19%), Mexico (14 %) Vietnam (7%), Japan (3%)

Table 3
Importers of sawn timber.

Country (Listed by largest importers)	Average Distance of imports (km)	Top import countries (2021 – ITC)
USA	2,647	Canada (79%), Germany (7%), Sweden (2%)
China	7,041	Russia (38%), Thailand (13%), USA (11%)
United Kingdom	1,818	Sweden (33%), Latvia (19%), Finland (10%), Germany (9%)
Japan	8,503	Canada (34%), Russia (15%), Sweden (13%), Finland (11%)
Germany	1,402	Austria (19%), Russia (16%), Sweden (10%) Czech Republic (9%), Finland (9%)

A3 – Manufacturing

Module A3 includes the carbon emissions of the processing and fabrication of timber products. This can be distinctly split into three parts: the processing of the raw materials, the kiln-drying of the timber (whereby a proportion of the moisture is removed) and the fabrication of the sawn timber into a variety of timber products. The A3 module typically accounts for 5-10% of the A1-A5 carbon emissions of a timber product, because biomass energy is typically used in timber manufacturing. Significant reductions in carbon emissions have been seen in recent EPDs, reflecting increased use of renewable energy in the local electricity supply and also renewables and biomass CHP used on the production sites. Refer to the IStructE's guide for "Mass timber embodied carbon factors". Figure 10 shows the typical supply chain process for CLT and Glulam products and the carbon contribution to the A1-A5 stages.

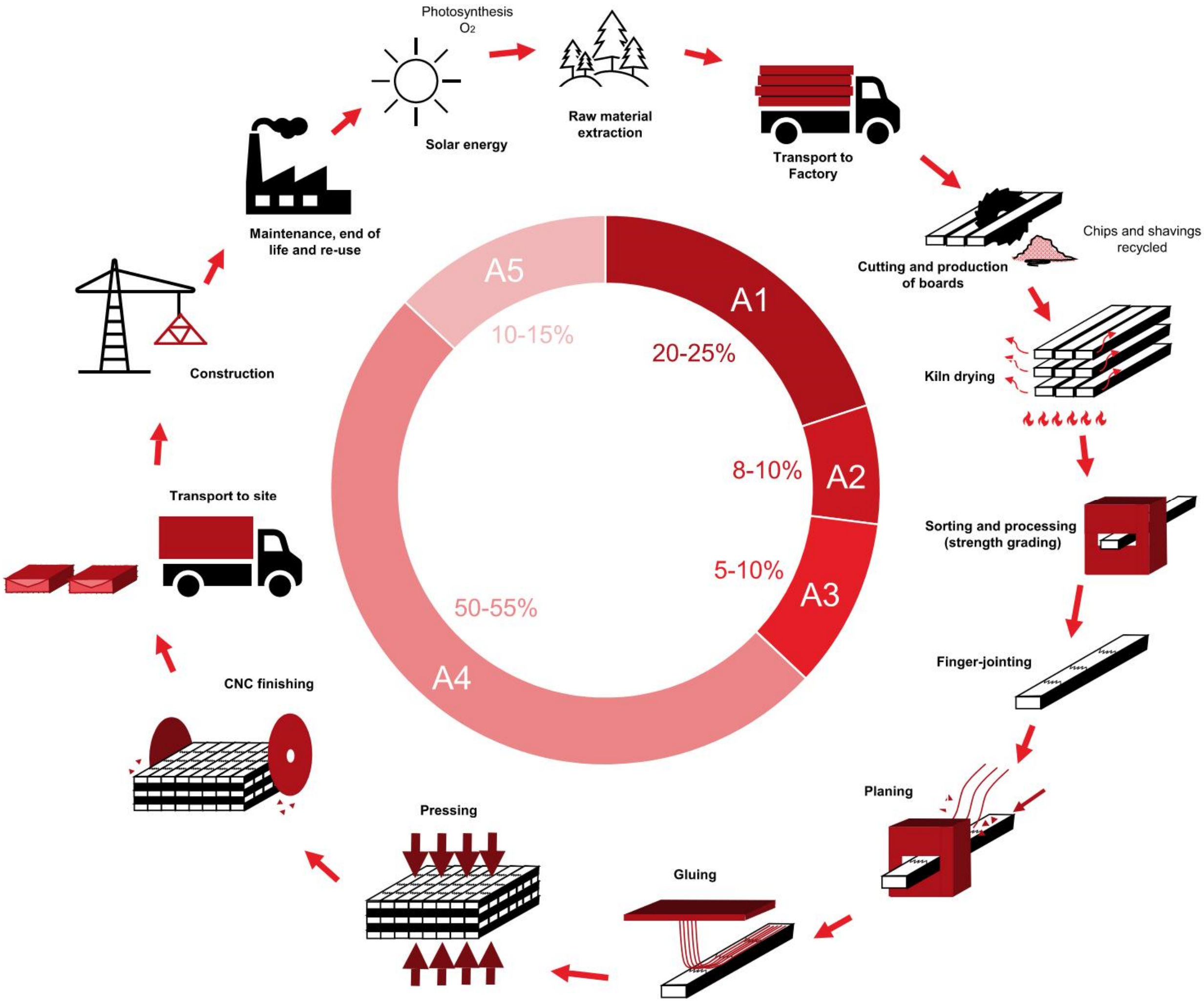


Figure 10
Typical supply chain process for CLT & Glulam products [15].

Reused and recycled timber

Sourcing sustainably also requires utilising wood more efficiently to meet construction demands by reusing and recycling wood products via the cascading principle shown in Figure 11, before eventually being burnt for energy [16]. It should be noted that there is a hidden CO_2 emission in the burning of tree waste and residue. This could be a significant value, which is controversial in biomass power production. It is worth noting that this would still be considered carbon neutral by LCA standards, since the biogenic carbon both enters and leaves the system. The concept shows how cascading can optimise wood utilisation to enable preservation of forests; however, it must be noted that fossil fuels are still required to re-purpose re-used timber products.

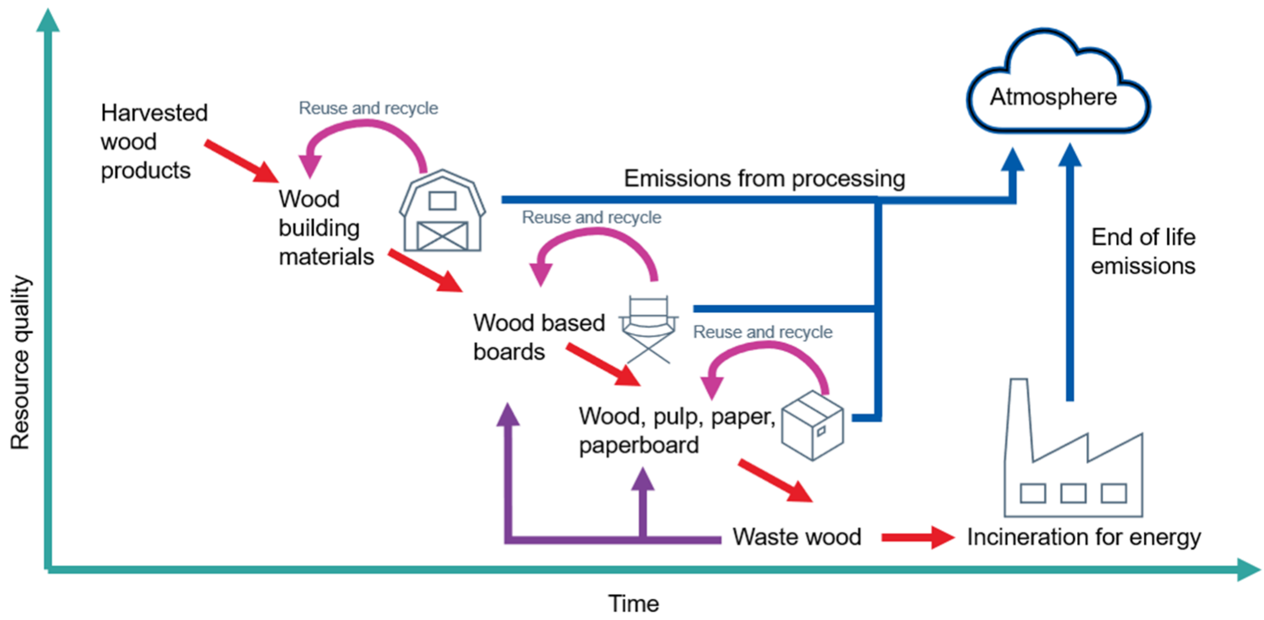


Figure 11
The ideal 'cascading' system of wood utilisation, reuse, and recycling [17].

Stripping and cutting

Once the trees have been cut into logs, they are transported to the sawmill. Each sawmill will receive logs from multiple (typically) local forests.

At the sawmill, the bark will be stripped, and the logs are sawn into the required section sizes. Any tree waste, including sawdust, is used in the manufacture of other types of timber products or is burnt for energy (Figure 12) [1].

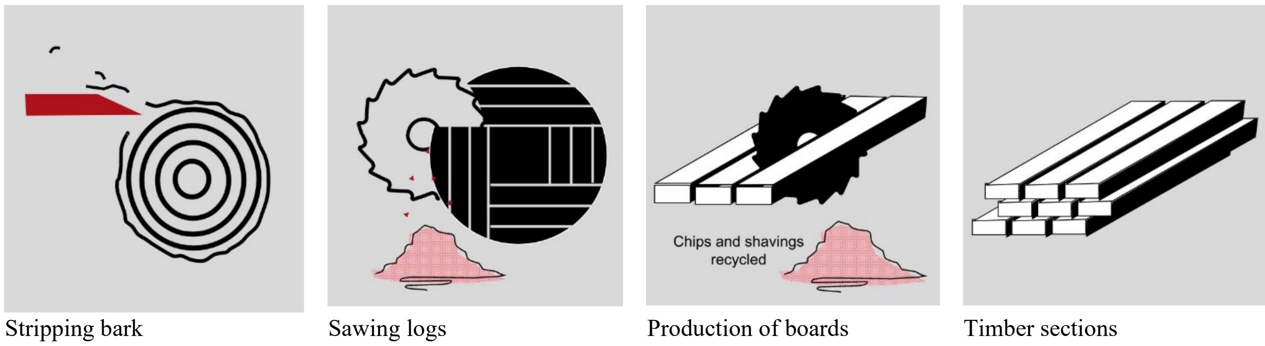


Figure 12
Processing of timber at the sawmill.

Kiln-drying

The timber is subsequently kiln dried. This is a controlled process at the sawmill where the timber is dried. The fresh wood is seasoned at the sawmill where it will be dried to approximately 12-18% moisture content or to the requirement of the final user. The kiln drying process is usually fuelled by either natural gas, or using offcuts and forest waste. While timber can also be 'air seasoned', this alternative process takes months; therefore kiln drying is always used by commercial mills as this takes only a matter of days for the softwoods typically used for Glulam and CLT.

Sorting, gluing and finishing

The kiln dried timber is then transported to the manufacturing site and is graded according to its strength properties, with similar strengths being grouped together. Depending on the final product, the manufacturing process may vary; typically, flaws in the wood such as knots and other defects are cut out at this stage. The softwood can either be finished to be used for internal finishes, or it can be processed further to create CLT and Glulam engineered products.

CLT and Glulam can be manufactured to custom sizes. Maximum sizes of elements are generally governed by transport. Both engineered timber products follow a similar finishing process as follows (Figure 13):

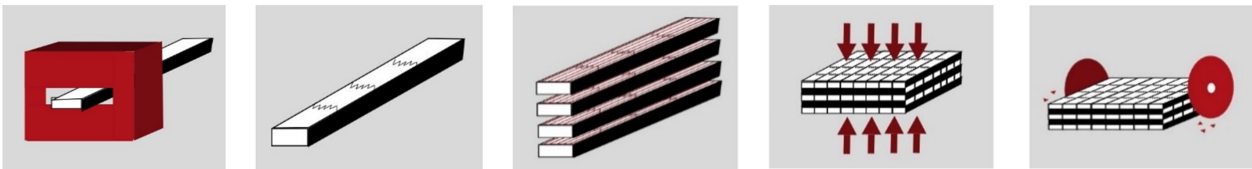
1. **Finger jointing:** The individual graded boards, named 'lamellas' are finger-jointed and interlocked with an adhesive joint allowing long lengths of laminates to be made. Each lamella is then planed. Planing the lamellas can contribute to high levels of waste.

2. **Adhesives:** Once the finger joints have set, adhesive is then applied to the faces of the laminates. The main difference between CLT and Glulam products is the direction of the grain when each layer is bonded. CLT normally consists of 3 to 7 layers with each layer at right angles to the grain in the previous layer. Glulam has each laminate layer in line with the grain. The glue lines in both products are very thin - generally less than 1% of the depth of an element.

3. **Pressing:** As the glue is applied, the layers of laminate are stacked and pressed together. The timber must be pressed for long enough before it is released, and the pressed timber must not be put under stress immediately after – a period of rest is required. CLT panels are usually pressed hydraulically, and hence large panels can be created. Glulam is pressed within a press bed and can easily be pressed into bespoke shapes to create curved elements.

4. **Finishing:** Once the adhesives have cured, the engineered timber can be cut into final shape, sanded and any final sealants can be applied.

Typically, EPDs for timber products report the embodied carbon equivalent impact for all parts of the manufacturing process as a single figure. Details of the relative contribution of each part of the manufacturing process are not readily available. Those engaging with suppliers of timber products are encouraged to query suppliers to better understand the relative contribution of these processes.



Sorting and processing | *Finger jointing* | *Gluing and bonding* | *Maintaining pressure* | *CNC finishing*

Figure 13
Fabrication and manufacture process of CLT and glulam.

Fire protection

If exposed to a fire, timber elements will ignite, and flame will spread over the surface. The rate of spread of flame can be reduced by the application of an intumescent paint by an impregnation treatment or through encasement by boarding.

Once the fire is established, the timber burns from the outside and an insulating char is formed on the surface of the wood. Whilst this has no mechanical strength, it insulates the unburnt timber behind. For softwoods, the char builds up at a known rate of approximately 0.7mm/minute which has been demonstrated by small scale testing [7]. Using this char rate, the time to the point which the remaining cross section of the member is too small to sustain the applied load can be estimated. For typical Glulam and CLT member sizes and a typical 60-minute fire resistance period, the reduced cross-section due to charring is often balanced by the lower loads and increased strengths which can be considered during an accidental fire situation. For smaller cross-sections and/or longer fire resistance periods, it will often be necessary to oversize the member to accommodate the fire case, but this will also contribute to the members overall embodied carbon.

An alternative to the reduced cross-section method is using plasterboard/fire rated board. This may be required by the fire strategy in areas where it is deemed the risks posed by exposed timber cannot be tolerated. Table 4 outlines typical quantities and thicknesses of fire board to achieve different periods of fire resistance. Exact requirements will be manufacturer specific and will have been demonstrated via appropriate fire testing.

Table 4
Required quantity and thickness of fire board to provide encapsulation to timber elements.

Period of fire resistance (minutes)	No. and thickness of encapsulation layers	Fireline board (Finland) $kgCO_2e$ [18]	Firecase board (UK) $kgCO_2e$ [19]
30	1 x 18mm	3.6	4.476
60	2 x 15mm	6	7.46
90	2 x 19mm	7.2	8.954
120	3 x 15 mm	9	11.19

Moisture control

Water damage is a large source of insurance claims for timber structures [20], so a moisture control plan is vital in design, construction and operation. Exposure to moisture during construction and use may damage timber products in the long-term and lead to mould and/or rotting of timber elements. Structures should be designed to avoid standing water, hidden leaks, and reliance on roof membranes alone without a second line of defence. In critical areas, consider designing in two lines of defence. Where additional sealants or chemical treatments are specified, it is important to note that this may impact the ability of the timber to be recycled. Similar consideration should be given to acoustic and dynamic design.

A5 – Site construction

CLT and Glulam elements are commonly prefabricated and hence allow for quick installation times on site, with small installation crews. Decreased construction times reduce construction costs as well as provide the opportunity to reduce the overall A5 construction emissions of a project. Timber elements designed to be internal should be kept dry during construction but are resistant to minor water exposure as long as they are allowed to dry out. Suppliers will often provide a thin surface sealer on Glulam and CLT elements to prevent staining.

Site waste – permanent timber

Prefabricated engineering elements such as CLT/Glulam usually always come to site ready to be installed, hence there should be little waste at this stage of the process. Sawn softwood timber products that are frequently cut to fit on site will produce waste when being installed; however, if this is segregated properly, it should be easy to recycle. Treatment is relatively common for sawn members used for light frame walling: sawn timbers used internally would generally not be treated. For reference, WRAP offer a waste rate for various timber products [21].

Site waste – temporary timber

As well as high grade engineering timber products, the flexible and lightweight properties of softwood often lend themselves to be useful for the transportation of materials and for site hoardings and concrete formwork. One of the important things to consider with temporary timber being used, is that the benefits from sequestration cannot be taken into account as it does not form part of permanent works and hence the biogenic carbon is not 'locked in' and leaves the product system. When designing concrete structures, designers should consider how the use of timber shuttering can be reduced, using formwork systems like PERI. When designing concrete structures, designers should consider how the use of reusable formwork systems can be adopted to reduce site waste overall.

Stage B

Keeping timber dry is the key to long term durability. Structural timber should generally be protected from water exposure with an overhanging roof or similar to prevent decay. Particular care should also be taken with flat roofs, and wet rooms to prevent leaks. This may imply a more robust waterproofing design and more rigorous maintenance requirements than other construction materials.

Stage C

The carbon sequestered from timber being re-used should be accounted for in Module C. At end of life of a building (life cycle stage C), biogenic carbon is either transferred to another system through reuse or recycling, or it is emitted back to the atmosphere through incineration or decomposition. Although end of life transfers of biogenic carbon through reuse and recycling do not result in any real emission of GHGs back to the atmosphere, current methodologies do not differentiate them from real emissions of GHGs due to incineration and decomposition.

Timber does have a reputation for high end-of-life emissions, but these are predominantly virtual emissions associated with removing biogenic carbon from the calculations. Both emissions and transfers of biogenic carbon are aggregated in one number for life cycle modules C3 and C4 combined. However, it should be noted that these end-of-life assumptions are uncertain as they are a prediction of practices to be used at the end of the building life cycle. The time value of carbon is important and should be considered as part of a dynamic LCA, because carbon emitted now is more dangerous than future carbon emissions in relation to meeting global targets.

Stage D

Module D is only the negative emissions from displacement of typical products from recovery or recycling, e.g. electricity generated from biomass. According to the Wood Recyclers Association (WRA), 4.5 million tonnes of wood went to waste in the UK in 2018, with 40% of this waste coming from construction and demolition. From this total value, TRADA research suggests that 83.4% of this waste was burned for energy or downcycled into new products, and less than 1% of waste wood is sent to landfill [22]. Figure 14 shows the estimated wood waste in the UK in 2018 and the re-use applications.

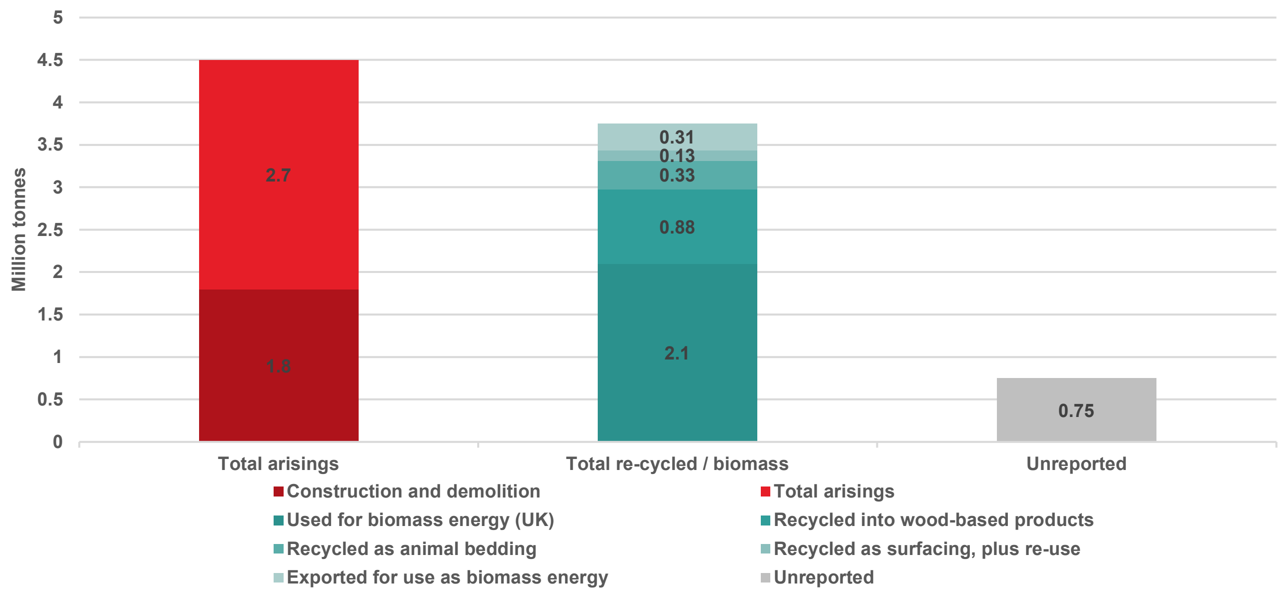


Figure 14
Estimated UK wood waste arisings and recycled applications in 2018 [22].

Timber waste specific data from EPDs should be used where possible, however if this information is absent, the following rates could be used for the corresponding circumstances [23]:

• Landfilling – no landfill gas recovery: 2.15 kgCO_2e/kg of timber product.

• Incineration: equal to sequestered carbon

Both Timber Development UK [23] and the RICS Professional Statement on whole life carbon, which are based on the requirements of EN 16485 (c-PCR for timber following EN 15804) and EN 15804+A2), require the impacts from incineration, recycling or landfill to be reported in Module C3 (recovery) or C4 (disposal). When timber leaves the system if it is recycled or reused, then the sequestered carbon must be transferred to the next system and reported as an emission in C3. If timber remains in landfill after 100 years, then the sequestered carbon must be considered as a transfer to nature and reported as an emission in C4.

Recycling

Engineered timber products are mainly mixtures of timber and various adhesives, therefore making it difficult to recycle. At best recycling is likely to involve downcycling by cutting down larger structural sections into smaller cross-sections for non-structural uses.

Reuse

Timber elements can last centuries if well maintained. This demonstrates, that in principle. Well maintained timber elements can be reused at the end of life of the building. Design for disassembly should be prioritised alongside a robust maintenance strategy. Note that the use of chemical adhesives, preservatives, coatings and fixings may limit the reuse potential. However, timber suppliers do not currently offer scope for timber reuse due to the risk of proving the quality of such members in old buildings. [11].

Sequestration and effects on carbon calculations

As trees grow, they remove carbon dioxide from the atmosphere via photosynthesis. This natural process is known as 'sequestration'. The carbon element of the carbon dioxide sequestered is stored in the timber and is known as 'biogenic carbon'. Biogenic carbon is temporarily stored until is it re-released to the atmosphere or the ground at the product's end of life in the form of methane or carbon dioxide (CH_4 and CO_2) through incineration or decomposition. The longer the biogenic carbon is stored in the timber, the greater the climatic benefit, as it reduces the time over which that carbon is in the form of a GHG contributing to global warming. What happens to the timber at the end of life of a project determines how long the biogenic carbon is stored in the timber product, with the most beneficial outcome being for the timber product to be reused across as many project life cycles as possible, keeping biogenic carbon stored for as long as possible.

Embodied carbon calculations should reflect the reality that biogenic carbon is stored in timber products. However, a lack of consensus on how to account for the associated impacts, and likely a widespread lack of understanding of impacts of wider forestry practices and forest carbon flows has led to inconsistencies in accounting for sequestration and biogenic carbon storage. There are inconsistencies from country to country, but also within countries. There is currently no single method that accurately represents the full climatic impacts of temporary biogenic carbon storage through the use of timber products in construction.

Some approaches to calculating the embodied carbon of timber products ignore the sequestration, whereas others account for biogenic carbon entering the LCA at product stage A1-A3, but then remove it again at the demolition stage, with no assessment of the benefit accrued for the storage period, (as used in EPDs). EN 15804 considers a simple approach which ignores biogenic carbon, recording it separately. Dynamic LCAs attempt to address the time element by considering the "radiative forcing" (the radiative forcing is the difference between the incoming and outgoing radiation in the atmosphere. A net gain of energy will cause warming, and it is an index of the factor as a potential climate change mechanism) of future emissions relative to current emissions. Adjustments for future emissions (such as predicted grid decarbonisation) are more common in operational carbon assessments, but less common in embodied carbon assessments. There are also two approaches to treatment of biogenic carbon in dynamic LCAs – carbon captured in historic tree growth, or the regrowth needed to restore the biomass removed [24].

There are many unknowns in the calculation of sequestered carbon, and the benefits may be less than in initial assumptions. The amount of carbon sequestered can be assumed as -1.64kgCOe per kg of timber when product-specific data is not available [5]. Otherwise, follow guidance provided in EN 16449 [23].

Methodologies

Depending on how sequestration is treated in embodied carbon calculations, the perceived benefits of using timber to reduce embodied carbon can vary greatly. Below are the most common methods for accounting for sequestration and biogenic carbon around the world, with an appraisal of each.

Method 1: Timber is carbon neutral in relation to biogenic carbon.

Method 2: Biogenic carbon is always accounted for in life cycle modules A1-A3.

Method 3: Biogenic carbon is only accounted for in A1-A3 if lifecycle modules C3 & C4 are also calculated.

Depending on the scope of calculation, sequestration can be evaluated in two ways:

- Modules A1–A5: report sequestration separately alongside A1-A5 carbon emissions
- Modules A–C: include sequestration in the whole-life carbon assessment. To capture the differences, you'd need to expand the assessment scope to include subsequent products.

Although this can be used to qualitatively explain the benefits of biogenic carbon storage, it is difficult to make direct comparisons to schemes that do not use timber products, e.g., reinforced concrete and steel structures.

Method 4: As method 3 but with biogenic carbon reported separately alongside A1-A5 and A-C results.

This is typically used within Arup, as it clearly states the impact of the biogenic carbon, enables effective comparison against alternative schemes, and discourages inefficient use of material.

Method 5: Time value of carbon is accounted for.

Method interpretations

These approaches do not accurately represent the full climatic impacts of temporary biogenic carbon storage and use of timber products, for the following reasons:

- At end of life of a building (life cycle stage C), biogenic carbon is either transferred to another system through reuse or recycling, or it is emitted back to the atmosphere through incineration or decomposition. Although end of life transfers of biogenic carbon through reuse and recycling do not result in any real emission of GHGs back to the atmosphere, current methodologies do not differentiate them from real emissions of GHGs due to incineration and decomposition. Timber does have a reputation for high end-of-life emissions, but these can be predominantly virtual emissions associated with removing biogenic carbon from the calculations. Both emissions and transfers of biogenic carbon are aggregated in one number for life cycle modules C3 and C4 combined. However, it should be noted that these end-of-life assumptions are uncertain as they are a prediction of practices to be used at the end of the building life cycle.
- Climate change impacts of GHGs vary with the characteristics of the specific GHG and the timing of their emissions. The CO_2e (carbon dioxide equivalent emissions over a 100-year period) metric that is typically used on LCAs does not capture the temporal aspects of this. Generally, the longer a GHG is in the atmosphere, the greater the impact it has on global warming. The fact that biogenic carbon storage in timber delays the re-release of CH_4 and CO_2 into the atmosphere means that the emissions at end of life have a lower impact on global warming than if they were emitted at the start of the project (as per other materials). Calculating temporal climate impacts by using a time-dependent absolute global warming potential metric would help to show the true benefits of biogenic carbon storage.
- The impacts of forestry practices on carbon stored in the soil are not accounted for in LCA methodologies yet. The potential impacts of this are not yet fully understood.

Route to Net Zero

Timber as a structural material can be a distraction from the challenge of reducing the amount of material we use. If you can reduce structural demand by reducing spans, live loads, and acoustic and dynamic performance requirements, then that should be done first. Note that there is relative ease with which fossil carbon can be reduced for timber in future, through electrification of forestry, processing and transport, compared to portland cement and virgin steel which both rely on developing carbon capture technologies, which has more significant technical challenges.

It is important to understand the types of projects where timber can offer a real carbon benefit and to make the right design decisions to ensure that the benefits of timber can be maximised. Promoting alternative faster growing crops (such as bamboo) should also be considered, to assuage the pressures relating to sustainable forestry. Increasing our forested land is also key to managing demand and ensuring timber is available for future generations.

The extent of timber used on a project should vary depending on appropriateness, including durability, strength, and fire safety. Hybrid structures often provide the lowest overall carbon option, but it cannot be considered to replace all steel or concrete structures.

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