Carbon Accounting for Building Materials

An assessment of Global Warming Potential of biobased construction products

Non-technical Summary

Commissioned by
ECP/Cerame-Unie/ECSPA/EAACA/EMO/GCCA
Reference nr.
R086049aa.225DRY10.djs
Version
01
Date
June 8th, 2022

Authors
Dirk-Jan Simons
Gerwin Beukhof
Harry Croezen (Royal HaskoningDHV)
Hilko van der Leij
Els Ribbers
Matthew Doe (Royal HaskoningDHV)
Jeannette Levels
David van Nunen
Susanne Visch

Table of contents

1 Introduction

Achieving a net-zero carbon economy by 2050 is one of the key pillars of the European Green Deal. Evaluating the environmental effects of construction materials and products in an objective way is one of the preconditions for taking the right measures and decisions to mitigate climate change.

The Global Warming Potential (GWP) is one of the impact categories for Life Cycle Assessment (LCA), a scientific method used to analyse the environmental impacts of goods and services through their entire life cycle. In the construction sector, this method is used to develop Environmental Products Declarations (EPDs), the "building blocks" on which full assessments at building and infrastructure level are performed.

Within that perspective, a collaboration between European and global key players in the field of construction products formed a consortium to expand the scientific knowledge around GWP assessment methodologies. This consortium commissioned the research gathered in the underlying report. This study, a collaboration between LBPSIGHT and Royal HaskoningDHV[1], provides an assessment of the science base behind the principles of carbon storage in (construction) products made of timber, the impact of mass-supply of timber on the European forestry production chain, the way greenhouse gas emissions and GWP are accounted for in environmental impact assessment methodologies (specifically life cycle assessment and the underlying databases), and what the potential of temporary carbon storage is for mitigation of climate change. Within the context of this study, the regulatory framework at the European level as well as at selected EU Member State level was assessed to provide insight into the status, specifics (in terms of what and when), clarity and applicability of policies, roadmaps, and standards.

The findings of this study can also be applied to other construction product sectors, and will hopefully improve clarity and transparency in making a discerning contribution to sustainability goals.

1 Royal HaskoningDHV provided the exploration of the wood supply chain.

2 The global carbon cycle

In the Earth system, carbon is present or stored in the lithosphere (as carbonate rocks), sediments (as organic matter or carbonates), ocean and freshwaters, soils and terrestrial biomass, and the atmosphere. By far the largest dynamic reservoir of carbon is the deep water of the oceans, of which it is estimated to contain approximately 80% of the Earth System's carbon (excluding the lithosphere), see Figure 1. The boxed numbers represent reservoir mass or carbon sinks in petagrams of carbon (1 Pg C = 1 Gton C).

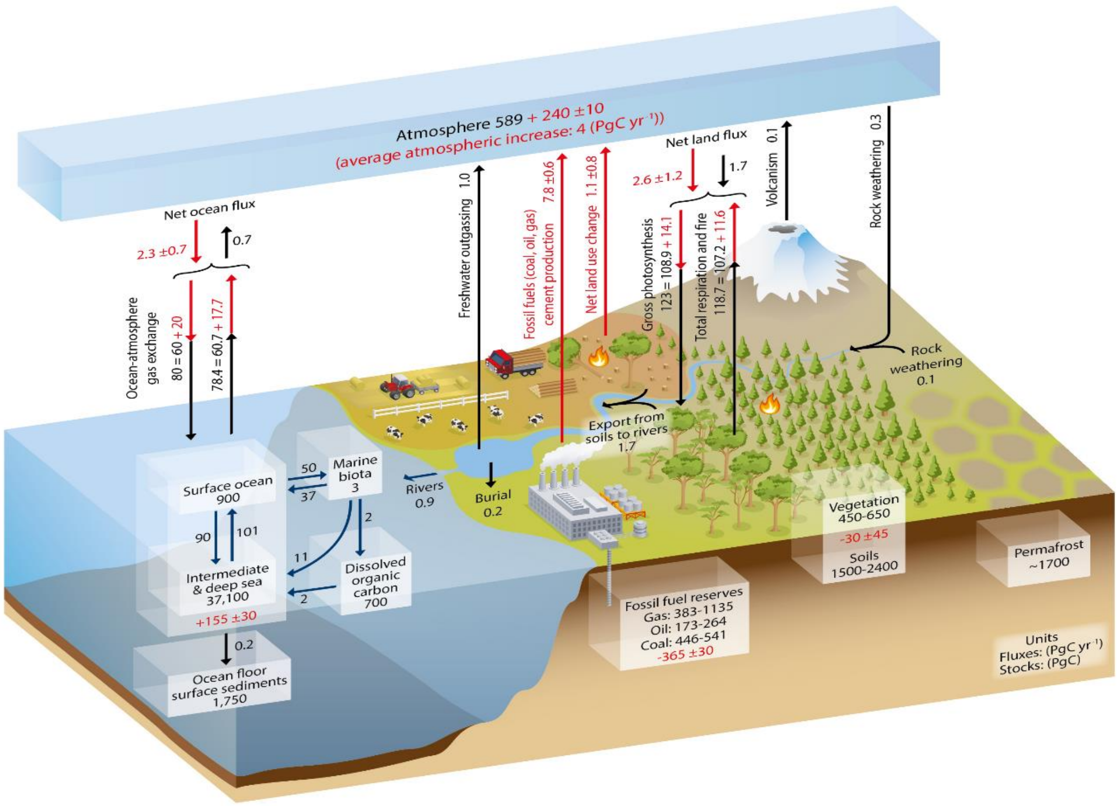


Figure 1

Graphic representation of the global carbon cycle (source: IPCC)

The global carbon cycle includes the mechanical, chemical, and biological processes that transfer carbon among these reservoirs. Reservoirs of carbon in the Earth system often are also referred to as "sinks" or "pools," and transfers of carbon between reservoirs are known as "fluxes". Carbon sinks for anthropogenic CO_2 stem mainly from physical ocean and biospheric land processes which drive the exchange of carbon between the different land, ocean and atmospheric reservoirs. The Northern Hemisphere provides the largest terrestrial sink, while the Southern Hemisphere has the largest oceanic sink. Ocean circulation and thermodynamic processes play a critical role in coupling the global carbon and energy (heat) cycles.

The combustion of fossil fuels and land-use change for the period 1750–2019 resulted in the release of approximately 2600 Gton CO_2 to the atmosphere, of which about 41% remains in the atmosphere today. Of the total anthropogenic CO_2 emissions, the combustion of fossil fuels was responsible for about 64%, growing to an 86% contribution over the past 10 years. The remainder resulted from land-use change.

3 Timing and effect of carbon storage

When carbon dioxide removal (CDR) is applied during periods in which human activities are net CO_2 sources to the atmosphere and the amount of emissions removed by CDR is smaller than the net source (net positive CO_2 emissions), CDR acts to reduce the net emissions. In this scenario part of the CO_2 emissions into the atmosphere is removed by land and ocean sinks, which historically and currently occurs.
When CDR removes more CO_2 emissions than human activities emit (net negative CO_2 emissions), and atmospheric CO_2 declines, land and ocean sinks will initially continue to take up CO_2 from the atmosphere. This is because carbon sinks, especially the ocean, show significant inertia and continue to respond to the prior increase in atmospheric CO_2 concentration. After some time, which is determined by the magnitude of the removal and the rate and amount of CO_2 emissions before to the CDR application, land and ocean carbon sinks begin to release CO_2 to the atmosphere making CDR less effective.

Within a geological timeframe, all storage of carbon is by definition temporary because of the Earth's system dynamics (e.g. plate tectonics). Carbon sinks eventually become sources through processes such as deep oceanic circulation and overturn, and subduction, metamorphosis and weathering of the carbon(ate) containing lithosphere. However, within the timeframe of post-industrial anthropogenic rises in atmospheric greenhouse gas concentrations, temporary carbon storage is within the realm of a 100 year time period up to the year 2100.

4 Review of the carbon neutrality principle

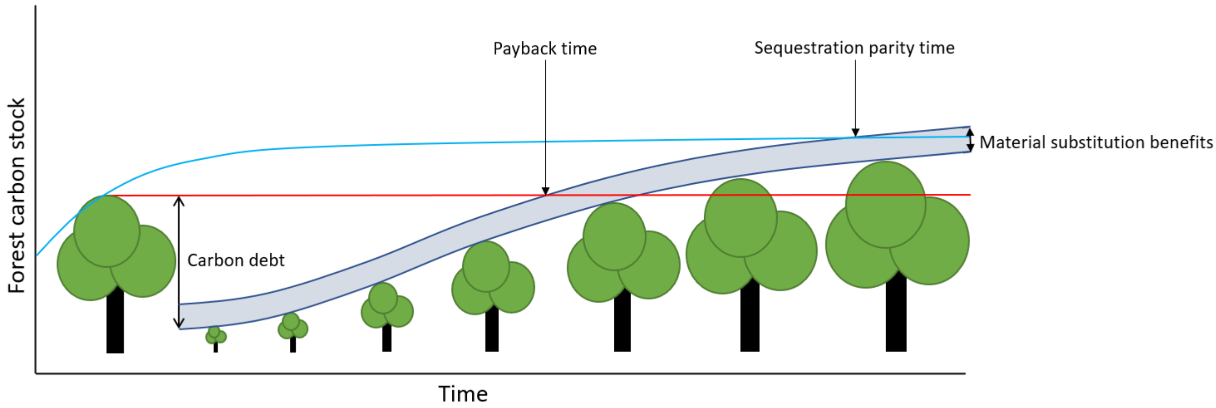
All countries signing the Paris Agreement, under the United Nations Framework Convention on Climate Change (UNFCCC), must decrease their greenhouse gas (GHG) emissions. A specific aim in the Paris Agreement is to achieve carbon neutrality in 2050. Carbon neutrality is achieved when all carbon emissions are balanced by carbon removals. In nature, this carbon neutrality is achieved automatically: all carbon emitted during the life cycle of an organism is eventually taken up again by (other) organisms, such as plants. However, anthropogenic carbon emissions currently exceed natural carbon removals, causing an imbalance in the atmosphere, which leads to climate change. To reach anthropogenic carbon neutrality in 2050, measures must be taken to increase carbon removals and decrease carbon emissions.

Forestry and subsequent biobased production are important climate mitigation tools available to governments, as atmospheric carbon gets taken up into the wood. If wood is used for long-lived wood products, carbon is effectively removed from the atmosphere long enough to indirectly limit or mitigate climate change. With wood stated as a carbon neutral alternative to fossil carbon based products, the question arises whether wood products are truly carbon neutral, and in which cases the neutrality principle might not hold.

In principle, a natural, unmanaged forest system is always carbon neutral: carbon emissions through degrading plant material and respiration equal carbon uptakes (sequestration) through photosynthesis. Harvesting trees removes the sequestered carbon from the forest system. A regenerating young forest compensates the carbon lost through growth of new trees. However, the regeneration time of the forest is longer than the period of carbon loss, causing a temporary carbon imbalance: the **carbon debt**. The time it takes for the new forest to balance the carbon debt by taking up as much carbon as was lost from the system after cutting is called the **carbon payback time**. If no harvest had taken place, the forest would probably have grown further and taken up more carbon until eventually stabilizing. The time it takes for the new forest after harvesting to reach the amount of carbon stored in the system if no harvest had taken place is called the carbon **sequestration parity time.**

Consequently, if wood is used in place of a more carbon intensive material such as plastic-based products, or traditionally produced concrete and steel, a net reduction of total carbon emissions occurs. From a consequential point of view, these avoided carbon emissions (otherwise called carbon omissions) through **material substitution** can also be taken into account in determining whether the material is carbon neutral. After all, by avoiding the use of more carbon intensive materials, the net carbon concentration in the atmosphere is reduced. However, the carbon neutrality of wood products also depends on what is done with the products after harvesting. For example, transport and processing of the raw wood material cause carbon emissions, as well as the burning and degradation of the harvested wood products at the end of the life cycle.

The dynamic between these factors is illustrated below. The blue line shows the carbon stock in the forest if no harvest had taken place. The red line shows the carbon stock in the forest at time of harvest.



However, when determining whether a **product** is carbon neutral through life cycle analysis (**LCA**) these carbon omissions from material substitution cannot be taken into account as the emissions from other materials do not influence the emissions from the product life cycle.

Therefore, in order for wood products to truly be carbon neutral, the growing forests' carbon uptake needs to equal the carbon emissions from land-use change, forest management, deforestation, transport, processing and eventual burning or degradation of the woody material. This brings both a spatial accounting and a temporal aspect to the challenge, as emissions and removals occur in different areas and over different periods of time.
As a consequence, mitigation options on the supply side are proposed by the IPCC that could improve the ability of production forests to act as carbon sinks (reducing deforestation, afforestation/reforestation, forest management, and forest restauration).

In general, a forest system can be either carbon positive, carbon neutral, or carbon negative, depending on the balance between emission, sequestration and omission processes. In the long term wood substitution of fossil carbon based products can be beneficial, if carbon uptake outnumbers emissions from forestry and the production processes of substituted materials do not decarbonise. However, in the short term, effects of increased wood use are negligible or may result in net carbon emissions. Increased efficiency and sustainability in the current production processes of other materials such as aluminium, steel and concrete potentially have greater impact.

When considering all factors influencing the carbon balance of the wood products, the term "carbon neutrality" becomes slightly ambiguous. Therefore, efforts need to be taken to include all aforementioned factors into a comprehensive life cycle assessment of wood products (and as such also other biobased materials).

5 Assessment of IPPC and EU Greenhouse Gas Roadmaps

5.1 IPCC and roadmaps

The Intergovernmental Panel on Climate Change (hereafter: IPCC) is a body of the United Nations studying the science related to climate change. The IPCC provides assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. These assessments are made by three working groups, each with its own focus.

Although the IPCC does not set global climate targets themselves, their assessment reports provide a scientific basis for policy makers around the world. For this purpose the panel created four future climate scenarios (Representative Concentration Pathways, hereafter RCPs) in its fifth assessment report and recommends actions based on the impacts of these. In the contribution of WGI to the sixth assessment report, five new climate scenarios (Shared Socioeconomic Pathways, hereafter SSPs) were introduced. These scenarios cover a broader range of greenhouse gas and air pollutant futures than the RCPs. It should be noted that this report is still subject to final editing.

Both RCPs and SSPs are labelled by the level of radiative forcing they reach in 2100. Radiative forcing is the difference between incoming and outgoing solar energy of the earth, given in W/m^2 and are translated in degrees Celsius global surface temperature increase.
Based on the fifth assessment report of the IPCC, the Paris Agreement was drawn up. Within this agreement, 196 countries from around the world committed themselves to limiting global warming to at most 2 degrees Celsius by 2100, with the aim of reaching the target of a maximum of 1,5 degrees Celsius warming compared to pre-industrial levels.

Nationally Determined Contribution
As a part of the Paris Agreement in 2015, all committed countries were required to submit a Nationally Determined Contribution (NDC), stating their plans to reduce GHG emissions and reach the 1,5 degrees Celsius warming target. These NDCs were updated in 2021 to include the most recent climate strategies. The United Nations Framework Convention on Climate Change (UNFCCC) has created a synthesis of these NDCs and compared these to the trajectories as set out in the IPCC special report on 1,5 degrees Celsius warming. It was concluded that, although estimated global emissions are reduced after the Intended NDCs were updated, current NDCs are still not sufficient to reach the target, see Figure 2 below.

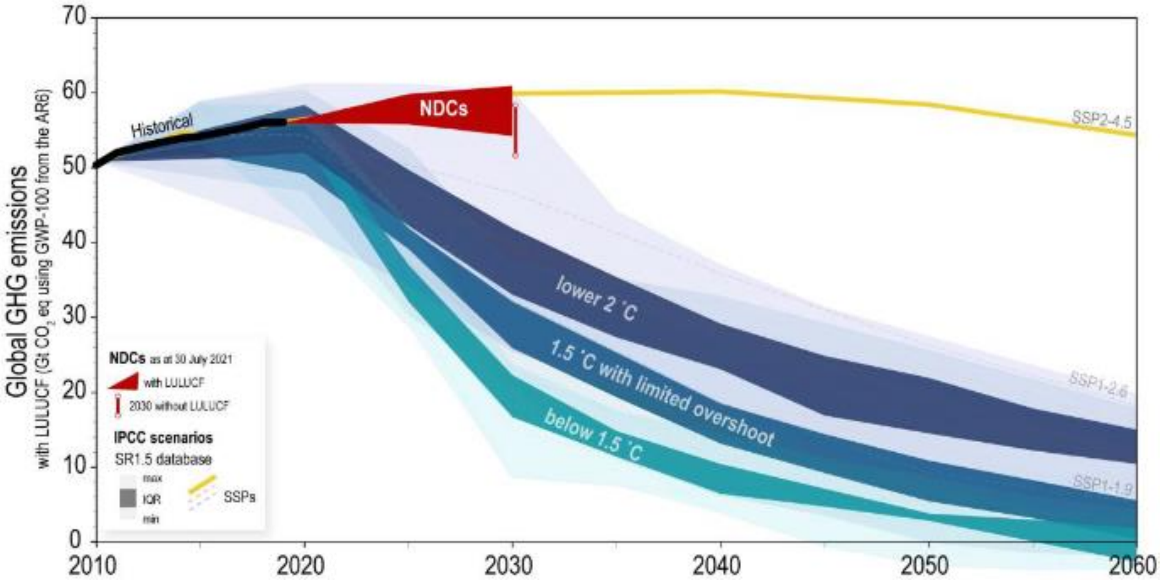


Figure 2
Summarizing global GHG emissions as needed to reach the 1,5 and 2 degrees Celsius warming targets, and the GHG emissions resulting from the policies set out in the NDCs. Source: UNFCCC

5.2 Assessment of EU Greenhouse Gas Roadmaps

In order to find the contribution of each EU member state to the global climate mitigation targets, an extensive literature search was performed. All publicly available documents that might specify a country's climate plans or greenhouse gas roadmaps were studied in order to find their climate change mitigation strategy. Additionally, seven EU member states were selected for more extensive investigation into their climate and forestry strategies. These states represent various climates and forestry management types:

- Austria;
- Finland;
- France;
- Germany;
- The Netherlands;
- Romania;
- Spain

5.2.1 Effort Sharing and greenhouse gas reduction targets

The European Union has set its own goal on reaching a low carbon economy by 2050. In order to reach this target the EU has set non-ETS (emission trading system) emission reduction targets of -10% over the period 2013-2020 and -30% over the period 2021-2030 compared to the 2005 levels.

In order to achieve these targets an Effort Sharing legislation was created, which established binding annual greenhouse gas emission targets for member states.

In addition to the Effort Sharing Legislation, in 2018 the "Regulation on the governance of the energy union and climate action (EU) 2018/1999" was adopted as part of the "Clean energy for all Europeans package", which was adopted in total in 2019. Within this regulation EU member states are required to submit a National Energy and Climate Plan (hereafter NECP). These NECPs ascertain compliance of the European Union member states to its Effort Sharing and LULUCF legislations. The NECPs result, on average, in a 95% reduction target of GHG emissions by 2050.

However, although most NECPs are very detailed, they are not concrete. As an example, Austria has mentioned that one of their targets for their forestry sector is to "Decarbonise and secure wood supply" and one of their measures to reach this target is "Preservation of the carbon pool in biomass and forest floors through sustainable forest management". However, the country does not specify when the wood supply needs to be decarbonized and by how much, how the carbon pool should be preserved, or what the country considers to be sustainable forest management.
Since no concrete climate roadmaps were available for any of the 27 EU member states, the following section only focuses on their forestry policies.

5.2.2 National forestry targets

Several documents were found to be relevant in determining the climate targets for the forestry sectors of the aforementioned seven member states. The first are the NECPs, in which the countries generally state their targets for the forestry sector. The second are the National Forestry Accounting Plans, in which member states determine a forestry GHG reference level against which future emissions and uptakes will be balanced. The third are the forestry strategies, which most member states have created to build on their forestry targets and measures to reach these targets.

National Energy and Climate Plans

As mentioned before, the NECPs of the EU member states are very detailed, but not concrete in terms of amounts and timelines. Although most countries state that their targets include sustainable forest management and the stimulation of biomaterials for energy production and carbon storage in wood products, none of the countries give any concrete measures towards reaching these targets. Furthermore, France was the only country of the seven that gave specific numeric targets for their land-use carbon sinks

National Forestry Accounting Plans

Under the EU regulation 2018/841 member states are held to a 'no-debit' rule, where all are required to balance their emissions from the forestry and land-use sectors with at least equal removals in the same sectors over the period 2021 to 2030. For forestry each member state must determine a reference level, against which emissions and removals from forest management (including harvested wood products) are accounted. The forestry reference levels are reported in National Forestry Accounting Plans. Although the forestry accounting plans do contain the states' reference level, no specific measures or targets are given that would show how the country plans to reach the no-debit target by 2030. Furthermore, as the countries are still in their first compliance period, no conclusions can be drawn on how (well) they are on their way to meet the EU targets.

EU and National Forestry Strategies
The EU Forest Strategy for 2030 sets a vision and actions to improve the quantity and quality of EU forests. Also, the Strategy aims to protect primary and old-growth forests, promote a sustainable forest bioeconomy for long-lived wood products, and ensure sustainable use of wood-based resources for bioenergy. The strategy is detailed and provides several concrete initiatives, of which the "The 3 Billion Tree Planting Pledge For 2030" is the only one with a specific roadmap for milestones. However, it is not currently implemented at the Member State level.

Some, though not all, member states have created national forestry strategies. These generally give an outline of the vision that the member state has for its forests. However, these strategies generally only date to 2025 or 2030, with limited outlines to 2050. Furthermore, again, these strategies do not contain any specifics and only give a general outline of the targets to be achieved in the country's forestry sector.

5.3 Conclusions on roadmaps

Based on the results found in this assessment, it can be concluded that the studied EU member states do have general visions for their climate and forestry sector, but not any concrete roadmaps in terms of specific targets and timelines. Leaving out the specifics brings about several risks. For example, by leaving out a specific time scale for a certain target and its measures, there is a chance that the concerning parties will not feel the need to change or take action. This would then lead to the target not being reached at all, or not in time. Furthermore, by not specifying how or where a certain measure should be taken, investments could be made in the wrong areas or methods. This greatly increases the risks of adverse effects, such as the loss of natural areas or a net increase in emissions.

If countries want to implement forestry as a climate mitigation method, and want to increase carbon storage in wood products, concrete roadmaps are necessary to accomplish this goal. Countries should make clear where new forests need to be planted, how these forests need to be managed and how much of the wood can be harvested. As this is currently not the case, the contribution of forestry to the IPCC's climate change mitigation scenarios of land-use change remain ambiguous at best. This in turn leaves the question unanswered whether increased demand and supply of timber for construction products may or may not adversely affect climate change mitigation goals and roadmaps.

The new EU Forest Strategy for 2030 can provide a good framework for this, but would also require swift implementation at the member state level into concrete roadmaps with actual timelines and milestones.

6 Consequences of mass supplying of timber: can supply meet demand?

6.1 Historic and current local and European supply of timber

Apart from the assessment to what extent an increased use of timber in construction products can contribute to mitigating climate change, the question arises whether such a shift in the use of raw materials can be accommodated in the first place. To gain insights on the balance between the capacity of forest to produce timber and the amount harvested and trade for consumption, the databases of the FAO, Eurostat and UNECE have been consulted.

These assessments provide an ambiguous overview regarding the European supply of timber, prohibiting a clear-cut quantification of the effect of potentially increased wood consumption on European forests. Several factors are the cause of this ambiguity, which is reflected in diverse findings.

Data on and definitions of forests and wood production vary across the geographic scope of the European Union's 27 member states. This results in gaps in reported data, corrections to bring all nationally reported data to a uniform definition and differing results between various sources of data. This is raised and reported in several publications.

The supply chain of wood and wood products is characterized by multiple flows and markets, making the national averages and figures not representative for a single wood product or forest activity. For example, particleboard is primarily made of wood residues from other wood products. This means that trees would not be harvested purely for the production of particleboard in a balanced global market. This cascading of wood resources means that wood products influence forest resources in different ways, in particular the type and amount of material used for a certain wood product. Hence, each wood production process will place specific demands on forest resources.

National averages and totals do not represent a specific local situation, meaning that on a local level the supply of timber might differ strongly from the national level. This explains why specific cases of illegal logging or otherwise ecologically unsound forestry are not reflected in the national data. This should be kept in mind when focusing on specific numbers, as these are an average representation of a member state. Hence the average does not proof or disproof that extreme outliers can occur.

Despite these considerations, the combined forestry data suggest that the forest area within the EU expands, and that *apparent* demand can be met by its own supply. In fact, given that 75% of the average net annual increment is utilised, an increase in demand may not constitute an *a priori* shortage.

6.2 Wood balance of seven EU Member States

As follow up on the wood supply results of all 27 EU member states, a selection of seven member states was researched in greater detail. This was done to improve the insight into the wood balances per stage of wood processing, and to understand how these wood balances differ per member states.
The selected member states for further research are;

- Austria;
- Finland;
- France;
- Germany;
- The Netherlands;
- Romania;
- Spain

These member states were selected to cover a broad spectrum regarding geography, climate, forestry industry, trade relations, and wood industry.

The assessment of these member states indicate that data gaps persist with each member state, making the complete accounting of all flows in the wood balance impossible. In particular there are gaps in the total harvested wood, compared to consumption, and often there is no data on secondary wood production or the fraction used in construction. This limits the ability to make comprehensive and definitive conclusions.

Reflecting on the seven member states it is noticeable that wood in construction, or otherwise secondary production, makes up a small fraction of the overall wood balance, in the member states where data is available, despite these member states having a sizable wood processing industry and use of wood in construction.
The production of CLT and GLT is equal to about 6% and 1% of roundwood fellings in Europe's largest producers, Austria and Germany respectively. This indicates that the majority of wood in these member states find alternative applications, mostly as fuel and paper pulp.
Import tropical non-coniferous wood in the member states is often negligible compared to the overall wood consumption, perhaps reflecting recent legalisation on trade of tropical wood into the

European Union. A large part of the demand for roundwood is for coniferous wood, although varying per member states and end application.

6.3 Process efficiency assessment on waste scenario's

In the EU and the UK, approximately 56 Mtonnes of wood waste are produced annually in the various links of the wooden product chain. Of the total of approximately 56 Mton of wood waste, approximately 9 Mton is produced in the construction sector. The waste is released during construction, renovation and demolition. Part of the wood waste released by households (approximately 5 Mton/year) is also related to construction activities.
Certain amounts of produced waste wood are not registered, e.g. waste wood consumed in household heating (fireplaces) or open burning. The amounts related to these produced and burned residual material are not included in the statistics.

Treatments and statistics
Wood waste from the construction sector and other industrial sectors is partly transported separately to intermediaries and partly isolated from mixed construction waste isolated at separation plants and shredder plants. Wood waste from consumers is mainly disposed of and processed as part of mixed household waste.

Pre-processed wood waste is currently supplied to the following types of outlets:

- Animal bedding material
- Particle board producers (no sales to MDF or OSB producers, because of higher quality demands and oversupply of by-products from the wood product industry)
- Utilization for energy production

In particle board production wood is chipped, cleaned of contaminants, dried, bonded and pressed, after which the rough plates are sawn and sanded.
Utilization for energy production comprises both of co-combustion in coal-fired power plants or in industrial furnaces (e.g. cement clinker production) and combustion in dedicated biomass-fired power stations.

The allocation to the different outlets differ within the Member States of the EU, but the average EU waste scenario for wood products is currently 49,4 % recycling, 49.5 % incineration and 0,01 % landfilling. At the Member State level, the actual waste scenario in practice can deviate significantly from what is assumed as a representative waste scenario in specific Product Category Rules (used in LCA). The current Belgian PCR for EPDs for construction products, for example, indicates for the waste scenario for B-grade wood 5-15% recycling, 85-95 % incineration, and 0 % landfilling. Recent statistics, however, indicate 20% recycling, 20% incineration, and 60% unaccounted for or export. This also shows that waste treatment and application of wood waste is an international business, resulting in more GHG emissions from transport (which may not be accounted for in current PCR) and/or skewed representation of the waste scenario's applied in EPDs.

Competition for resources: economic driver to influence waste scenario
Recycling and recirculation of recovered post-consumer wood from the construction sector and packaging applications into new wood based products in practice only takes place in particle board production due to quality requirements for the raw material for the various other types of panel materials.
The share of recovered post-consumer wood in the raw material palette can vary from 15% to 75%, depending on the regional availability of recovered wood, but also depending on the regional availability of by-products from the wood processing industry.

In Northwest Europe, the particle board industry and waste wood combustion plants compete for the higher quality solid B-grade wood. For lower quality grades of B-grade wood and C-grade wood (panel board), there is no competition between raw material and fuel applications as waste of this quality cannot be utilized as a raw material in particle board production. In competition, market prices of waste wood and industrial by-products and the costs for upgrading waste wood to particle board quality determine whether waste wood is recycled or utilized in 'energy recovery'.

The assessment of waste scenarios shows that the sources and amounts of waste wood varies greatly among member states. This has potential ramifications for modelling waste scenario's in LCA's and subsequently the declared overall GHG emissions in EPDs. Currently, a discrepancy between the standard waste scenario's in PCR and present day EU practice is identified.
The magnitude of the impact requires further investigation.

In addition, the assessment shows a market economy driven variability in the balance between waste wood treatment options: a change in market price (and subsidies) can clearly cause the choice for a different waste treatment, resulting for example in the shift from wood waste as material reuse to wood waste as fuel in energy production. Effectively, such a shift also causes a change in the overall life cycle of the original wood material: a shift toward incineration will release biogenic carbon earlier into the atmosphere, and will therefore have a consequential effect on GWP/climate change mitigation.

6.4 Conclusions on consequences of mass supplying of timber

Overall it remains unclear whether supply and demand of wood in the studied European member states are in balance, and/or sustainable. This is due to the gaps in data, to complete the balance on both sides, and lack of information on how demand for wood in construction would influence fellings in forests.

The results are in line with those of the "Historic and current local and European supply of timber", especially regarding supply and trade in roundwood, although showing variation in terms of actual numbers. A greater level of detail has been achieved over the internal statistics used previously which, together with the context of reports, provided more depth. In particular the import/export countries and production of sawnwood and secondary wood of respective member states have become clearer. This gives more insight into where wood is sourced from, processed and finds it end application per member states than the previous results.
However with the data gaps and unknown causal relations between consumption of specific applications and fellings in forests, the exact balance remains unclear.

7 Assessment on consequential LCA of mass supply of timber

For this part of the study, all available academic publications of attributional and consequential life cycle assessment (LCA) on forest products (mainly the use of CLT) versus 'mineral' products (in these publications usually limited to steel and reinforced concrete) as of 2000 were reviewed and compared. Subsequently, consequential LCA was explored as a tool for the assessment of critical impacts that fall out of scope of conventional attributional LCA.

7.1 Attributional and consequential LCA

Most life cycle assessment studies aim to assess the impact of a specific product or service. The system modelling approach for such studies is called an attributional approach. In the attributional approach the in- and outputs are attributed to the functional unit of a product. It depicts the potential environmental impact that can be attributed to a product over its lifecycle, looking both up- and downstream of the supply chains of the concerning product. In essence it is a bookkeeping exercise with (mostly) clear system boundaries. Attributional modelling makes use of historical or measurable data with a high degree of certainty.

In a consequential life cycle assessment approach, activities within a product system are linked so that the activities are included in the product system to the extent that they are expected to change as a consequence of for example a change in demand for the functional unit.

Figure 3 demonstrates the fundamental difference between attributional and consequential LCA.

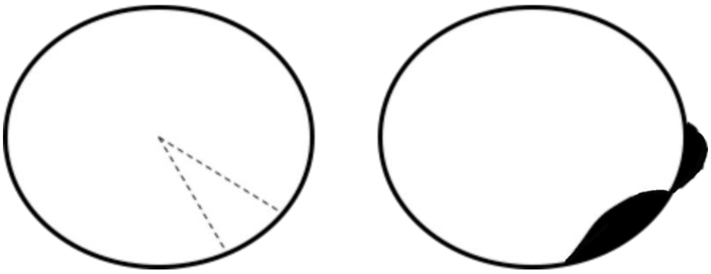


Figure 3
The conceptual difference between attributional (left) and consequential (right) LCA.

The circles represent the total global environmental exchanges. In the left circle, attributional LCA seeks to cut out the piece with dotted lines that belongs to a specific (human) activity, e.g. car driving or using biobased construction products. In the right circle, consequential LCA seeks to capture the change in environmental exchanges that occur as a consequence of adding or removing a specific (human) activity (e.g. an *increase* in car driving, or using *more* biobased product) .

Both approaches can answer different questions. The attributional approach can be used for comparative LCA. Consequential LCA's are used as a decision making tool and can answer policy related questions. It assesses (or should assess) all relevant environmental changes as a result of a policy shift.

7.2 Literature review on the use of forest products using consequential LCA

To answer the question whether large scale use of timber can contribute to achieving climate mitigation targets, we propose that an assessment using consequential LCA can potentially supply clear answers. This is due to the fact that the use of forest products leads to several high influential shifts in land-use and present supply chains, far beyond the direct product system.

A state-of-the-art (as of 2000) literature review was performed on the topic of forest products with the use of consequential LCA. Out of approximately 100 publications since 2000 on consequential LCA that were reviewed, eight publications addressed timber and forest products specifically.

Overall, it is noteworthy that the majority of the studies assign material substitution and end-of-life energy recovery as the main contribution to the conclusion of the study.

Seven out of eight reviewed publications conclude that the use of forest products in construction has a discernible abatement potential in climate change mitigation. The studies vary in geographical boundaries, subjected products and methodological variables, but the conclusion remains consistent. All reviewed studies used consequential LCA to look beyond the initial product system, but did differ in:

- substitution of conventional materials,
- substitution of end-of-life (EoL) energy recovery
- allocation of land-use for increased afforestation.

All studies assumed carbon emissions from conventional materials to be static, whilst assuming emissions from forest products to decline in the future due to production scale-up and innovation. This is a questionable assumption in the light of current GHG roadmaps, of which the majority impose significant carbon emission reductions across all industries.

Where energy recovery from End-of-Life was modelled, some studies assumed fossil energy carriers to be displaced, assuming energy use to be statically. However, it is not likely that no shift in the contribution of renewable energy to the total energy demand will take place.
Lastly, few studies considered land-use and the displacement of agriculture as a result of afforestation.

7.3 Considerations on the substitution effect

From the literature review of the consequential LCA studies, it becomes apparent that substitution of conventional materials by forest products in many cases has a dominant effect on whether the use of forest products in construction can have abatement potential for climate change (or potential to reduce GHG emissions). However, where some publications provide insight or details on the inventory of the wood product system, no essential details are provided for the conventional materials that are substituted. Typically, only the type of product is mentioned (e.g. concrete block, masonry wall), but not the specifics that are important for LCA calculations (e.g. type of cement, type of brick, e.g. calcium silicate or clay). Since many of the studies identify substitution to be the main contributing factor, the question how the LCA calculations of the conventional materials were carried out becomes all the more important. Without the specific information necessary for reproducing the input parameters of the consequential LCA models in these studies, the results remain ambiguous.

If substitution of conventional materials is of (potential) great importance in a consequential LCA study, it is recommended to pre-assess the impact of substitution modelling choices as a preliminary step before carrying out the overall consequential LCA calculations. This will help document and clarify fundamental assumptions and parameters, while also putting the results of the consequential LCA in the right perspectives.

To illustrate this, in a more general sense, a sensitivity analysis was published in 2019 on the key assumptions in product substitution of wood for more fossil carbon intensive building materials

which suppose significant climate mitigation benefits. By re-examination of the fundamental assumptions underlying these projections it was shown that long-term mitigation benefits related to product substitution may have been overestimated 2- to 100-fold in literature.
These reported findings clearly underline the importance of the assumptions and starting points for substitution effects in consequential LCA's.

7.4 Conclusions on consequential LCA

The current general scientific consensus is that when comparing timber products (CLT/GLT) with mineral products (e.g. reinforced concrete and steel) in comparative attributional LCA, timber products can have a lower contribution to GHG emissions. However, critical aspects such as availability of biomass and indirect (allocative) effects remain out of scope with attributional LCA. Consequential LCA has the potential to bring more clarity to these hidden aspects, as the scope allows for system expansion. Several academic publications using consequential LCA's on the topic of the use of mass timber in construction products were assessed. From reviewing these publications, a large variation is apparent in methodological choices, in particular on the topics of indirect effects, substitution effects and end of life scenario's.

Within the framework of the reviewed publications here, these studies conclude that the consequences of shifting to using (more) timber for construction, is beneficial to reducing GHG emissions. However, we conclude that without guidelines for consequential LCA, which reduce the variation in methodological choices, the results of these studies remain ambiguous and do not allow such clear-cut conclusions.

8 LCA database analyses and EPD assessment of GHG emissions

8.1 LCA databases assessment

As part of the review of Life Cycle Assessment (LCA) methods of biobased construction materials, an assessment of LCA background databases was performed. The purpose of this review is twofold: to gain insight in the manner in which biobased products are modelled in these databases and to investigate whether the modelling approach is representative of current production processes.

A manufacturer usually only has information of products within its own sphere of influence. LCA background databases are therefore a fundamental part of LCA, as they provide essential life cycle information to foreground data (see figure below) and of processes up and down the product value chain.

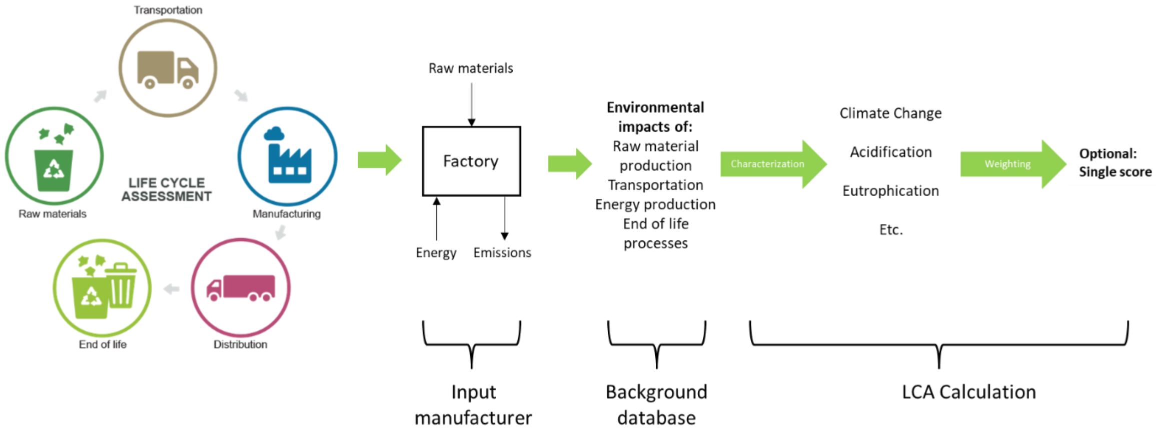


Figure 4 LCA calculation steps

Due to the large number of biobased construction materials and background datasets, the focus of this review was set on two important construction materials: beams and panels, both solid and composites, and made of hard wood and soft wood. The geographical scope of this assessment was set on Europe, with outlook to other regions where relevant. Efficiency of biobased production processes (forestry, sawing, planing) in background modelling was compared to recent statistics.

There are many LCA background databases in existence, varying from databases with a very broad application, representing many activities in many regions, to very specific databases for specific countries and/or specific product groups. There are two main databases in use for LCA calculations in the construction sector within Western Europe: Ecoinvent and Gabi.

The data quality of LCA background databases is determined by a number of factors, which include the age of the dataset, update frequency, completeness and geographical coverage. The age of the dataset can differ greatly. For example, the Ecoinvent database includes datasets for materials that have not been significantly reviewed since the early 2000s. However, certain parameters are regularly updated that indirectly improve data quality for a large number of datasets, for example energy inputs such as the electricity production mix.

Non-biogenic GHG emissions

Background processes within the database that make up the value chain in LCA modelling, have been screened on missing non-biogenic CO_2 emissions (e.g. missing transportation modes, missing underlying processes withing a dry kiln). This involved the screening of the network of underlying background processes of the different products. Obvious omissions or misrepresentations of such processes were not identified.

Biogenic GHG emissions

The main observation on biogenic carbon that was made is that within the modelling of forestry processes in LCA databases, all hardwood and softwood forestry processes are characterized as ‘sustainable forest management’. Furthermore, all biogenic carbon uptake in the forestry models is directly and only related to the carbon content of the wood product that forms the output of the forestry process. No uptake and no emissions are included from non-merchantable wood that remains in the forest, such as tree tops and roots. This implies that either the carbon neutrality principle is applied in the model, meaning that these emissions are compensated for by carbon uptake of the forest, or that for these components both inputs from nature and emissions from decomposition are missing.

Background documentation or other literature does not provide a comprehensive explanation for these observations. The definition of sustainable forest management that can be found indicates that sustainable forest management as defined by Ecoinvent does <u>not</u> include the principle of carbon neutrality. Therefore, we conclude that LCA databases do not provide a consistent explanation of how forestry processes are modelled in terms of carbon neutrality and environmental impacts.

8.2 Assessment of Product Category Rules and Environmental Product Declarations

As much as it is important to assess the LCA background databases, it is equally important to gain insight in the different sets of standards and rules that are currently in use when it comes to providing the scope and boundaries of LCA models, and applying or comparing the results from LCA calculations in Environmental Product Declarations (EPDs). The following paragraphs provides an assessment of these different standards and the product category rules (PCR) and its impact on selected EPDs of wood based products.

PCR
Product Category Rules are a set of rules, requirements and guidelines for developing Environmental Product Declarations for one or more product categories. PCR are particularly useful where the environmental impacts of products within a category group are to be compared.

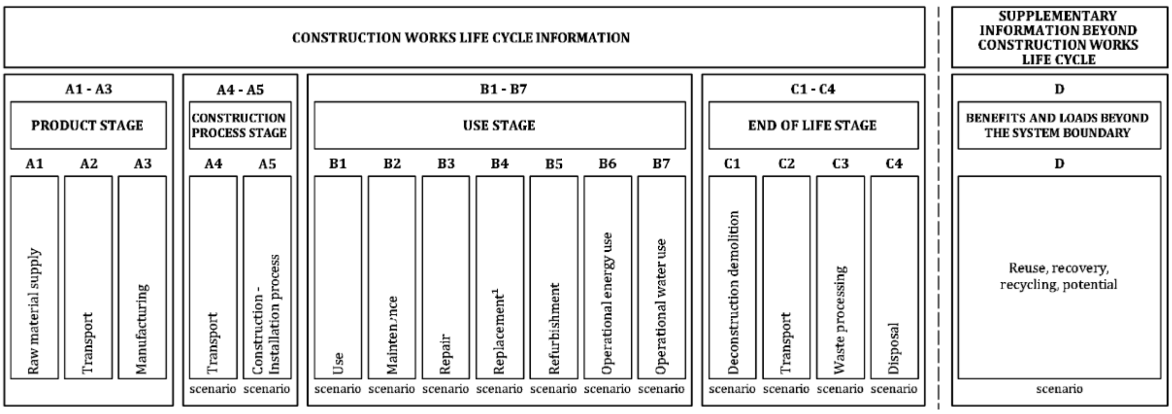
Standard EN 15804 “Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products” is the overarching standard for all EPDs on construction works. Since 2019, the amendment ‘A2’ has been added. With the modification to A2, the global warming potential impact category has been separated into global warming potential from fossil fuels, global warming potential from biogenic and global warming potential from land use and land use changes. The previous version (‘A1’) of the standard did not include this. In addition, differences in characterisation factors of GWP between A1 and A2 may lead to a difference in the results for GWP of up to 10-15%. Both versions of the EN 15804 will still be in use in the coming years, depending on which EPD program is used.

In addition, several PCR show differences in the way carbon neutrality is assumed or proven and how it is taken into account in LCA calculations. For example, standard EN 16485 (“Round and sawn timber - Environmental Product Declarations - Product category rules for wood and wood-based products for use in construction”) assumes carbon neutrality when wood comes from countries that can account for abiding to Art. 3.4 of the Kyoto Protocol or when the wood originates from forests that are operated under established certification schemes for sustainable forest management. If carbon neutrality cannot be assumed or proven, then the standard imposes that uptake of CO_2 cannot be declared.

EPD

The intention of Environmental Product Declarations (EPDs) is to present transparent, verified and comparable information about the life-cycle environmental impact of products and services.

The purpose of an EPD in the construction sector is to provide the basis for assessing buildings and other construction works, and identifying those with less environmental impact. As such, they form an important comparative tool. In EPDs several of the product’s life cycle stages are covered. These so-called modules (A, B, C and D) represent the following life cycle stages:



Of the 48 EPDs that were investigated (of which 11 in more detail), only a few mention the origin of the wood products. As a consequence, some of the products should not be eligible for carbon neutrality. As such, the declared values in the EPD in those cases, are incorrect when declared under the application of standard EN 16485.

Several wood product EPDs declare a negative sum of CO_2eq emissions over the life cycle. This is caused by the following: wood products enter the system with a negative biogenic CO_2eq since the carbon is stored in the wood (provided that this allowed according to EN 16485, which is not always clear). At module C3 the wood products are incinerated and approximately the same amount of carbon dioxide is emitted. However the wood products are incinerated with energy recovery and therefore environmental benefits are given in module D for the saved emissions from electricity and heat production from an alternative source. It is not always fully clear from the EPD with what alternative source the calculation of the benefits have been made. However, this can have a large impact on the overall result (and consequently the calculated GWP).

The assessment of PCR and EPDs of wood based products showed that inconsistencies both at the system level of PCR and the implementation in EPDs exist. Ultimately, this results in skewed declared values for biogenic CO_2eq emissions at the product level, and therefore in comparison with alternative products.

Proper alignment of these issues in PCR for wood based products and EPD formats, at least at the European level, is a prerequisite for fair comparison of GWP of different construction products. As a consequence, this means that a similar assessment of alternative construction products should be considered (but is not in the scope of this study).

9 Temporary carbon storage in Harvested Wood Products in construction

The effectiveness of terrestrial carbon sequestration through forestation options is based on the whole carbon cycle covering both carbon stocks and flows, and is influenced by human activities and their impacts on the biosphere and atmosphere when it comes to disturbances of forestry ecosystems. As a consequence, the same holds true for utilising harvested wood products in the construction sector as a temporary carbon sink.

In order to form a position on the potential of temporary carbon storage in harvested wood products (HWP, or timber) in construction, a literature review was performed on the topic of temporary carbon storage in the biosphere and biobased materials.
In this review based upon peer-reviewed literature, the focus was on publications as of 2000.

Out of approximately 80 publications since 2000 on temporary carbon storage that were reviewed, thirteen publications addressed the subject within the scope of this study. While literature has been found with a critical stance on temporary carbon storage, as well as a positive stance, most sources are neutral on the subject.

The common thread in all literature reviewed, is that potential benefits of temporary carbon storage very much depend on both the approach adopted to quantify these benefits, as well as on the accounting time horizon (= the time beyond which further impacts are not considered). If temporary storage is considered then it is common practice to adopt a 100-year time horizon, but the choice of this horizon seems arbitrary and not scientifically substantiated. Also, often the choices used as basis for accounting temporary carbon storage benefits are not made explicit and transparent. This makes it very difficult to compare results and to base any policy decision on.

At face value, temporarily storing carbon is equivalent to delaying an emission by the same number of years it was stored. This means that depending on the time horizon chosen for the quantification of benefits, the period of time over which its impact is considered decreases. In other words: the potential mitigation value depends on the timing of both sequestration and re-emission of GHG.

Some authors argue that any delay in re-emission is beneficial because it provides extra time to find or develop more effective climate change mitigation solutions. In order to have any benefits from temporary carbon storage in timber, carbon neutrality through sustainable forestry and parallel active reforestation are unequivocal prerequisites, which at present is not an a priori fact. Also, the influence of the rotation periods related to the biomass growth can be problematic when assessing the impact of bio-based products. Not all biobased products can be considered as carbon neutral in a short time horizon, due to longer rotation periods / slow growing times. This specifically applies to timber. Fast-growing biobased materials, such as straw, hemp, and bamboo, can be more effective in this respect by rapidly removing carbon from the atmosphere, especially when applied in products with a similar service life as for wooden or mineral based construction products.

From the different methods available for accounting temporary carbon storage in LCA, the one that includes the so-called $GWP_{net\text{-}bio}$ indicator offers the most holistic, but less practical, approach. This indicator more accurately includes the potential effects of lost uptake after harvesting biomass. This lost uptake takes into account the CO_2 that would have been taken up if the trees had been left standing. In other words, what would have been the maximum uptake if undisturbed. This is a method that takes land-use and land-use change (LULUC) into consideration. We would argue however that the benefits of carbon storage, as proposed in PAS 2050 and the ILCD handbook provides a fair and more practical solution for accounting in LCA, and adjust for a high degree of uncertainty in the End-of-Life scenario’s.

10 Mitigation potential of temporary carbon storage in HWP

Long term mitigation solutions are necessary to avoid climate change in the long term, but temporary solutions may play a positive role in terms of avoiding to cross certain critical and potentially irreversible climatic tipping points. The potential value of temporary carbon storage in terms of climate change mitigation in the long term is subject of ongoing academic discussion. When focusing on the construction sector, there are several approaches to store carbon in the built environment. In fact, implementing buildings as carbon sinks has gained status as a mitigation strategy and is promoted by several policy initiatives such as the Renovation Wave Strategy and the new European Bauhaus initiative.

It is therefore a valid question what the climate change mitigation potential of harvested wood products (HWP) in construction can be. The following paragraphs provide a first order assessment of the potential contribution of HWP to mitigate climate change, at the European level, and is put in perspective of EU emission reduction targets and global surface temperature.

10.1 Global GHG emissions and reduction efforts

Global net anthropogenic greenhouse gas (GHG) emissions amounted to 59 Gton CO_2eq in 2019. Historical cumulative net CO_2 emissions from 1850 to 2019 were approximately 2400 Gton CO_2eq. By comparison, the current estimate of the *remaining* carbon budget from 2020 onwards for limiting warming to 1.5°C has been assessed as 500 Gton CO_2eq.

The carbon budget is the maximum amount of cumulative net global anthropogenic GHG emissions that would result in limiting global warming to a given level with a given likelihood. This is referred to as the *total* carbon budget when expressed starting from the pre-industrial period, and as the *remaining* carbon budget when expressed from a recent specified date. The remaining carbon budgets are from 2020 onwards, which extend until global net zero CO_2 emissions are reached.

This results in a global GHG emission reduction effort of 981 Gton CO_2eq. up to 2050, or 3481 Gton CO_2eq up to 2100 (assuming after 2050 the global GHG emission is allowed to stay at 10 Gton CO_2eq/yr.

The recent IPCC draft assessment report indicates that buildings have the potential to contribute more than 20% to the global effort, see Figure 5.

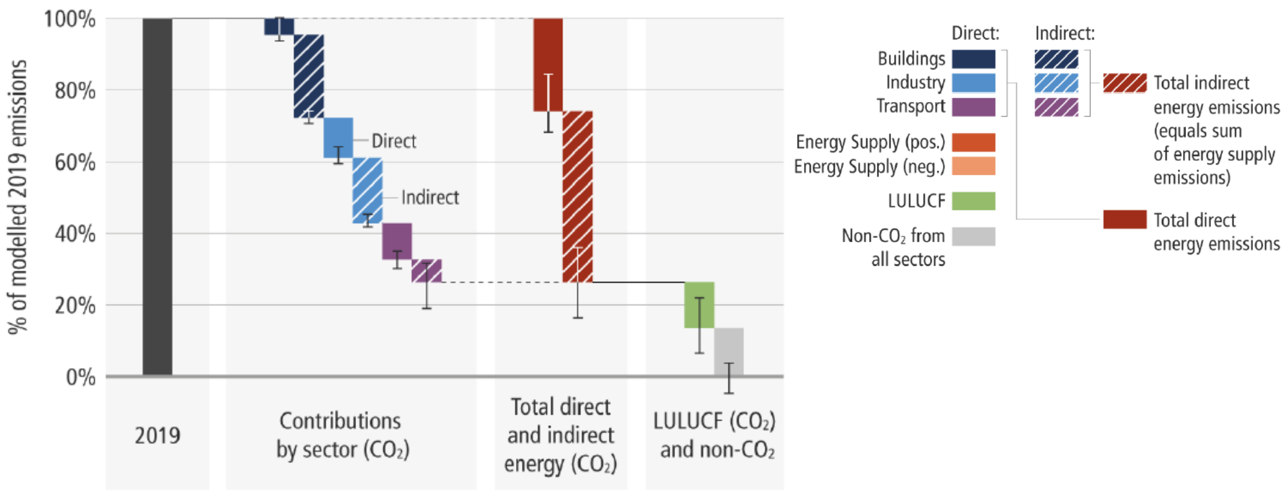


Figure 5 Relative contribution of different sectors and LULUCF to global anthropogenic GHG emissions. (Source: IPCC).

Specifically, global GHG emissions associated with buildings amounted to 12 Gton CO_2eq in 2019, equivalent to 21% of global GHG emissions. Of these 12 Gton, 81% of the emissions stem from offsite generation of electricity and heat, and direct emissions produced onsite (e.g. heating and cooking). Approximately 18% (2.2 Gton CO_2eq) are embodied emissions from the production of construction materials used in buildings. This means that the absolute maximum emission reduction potential from all construction materials in buildings can contribute no more than 6.5% to the total global effort up to 2050. This is assuming that *all* GHG emissions from construction materials are eliminated immediately (2.2 Gton CO_2eq/yr), which is not realistic.

10.2 Size of the net carbon sink for HWP in construction

Global potential

Since the publication of the IPCC's Special Report on Climate Change and Land several studies assessed the mitigation potential of the use of wood products (including but not limited to, HWP in construction). A global forest sector modelling study estimated that carbon storage in wood could provide an average mitigation potential (by increasing the HWP pool) of 0.4 Gton CO_2eq/yr for the period 2020–2050. This amounts to 10.7 Gton CO_2eq total up to 2050 (and 29.2 Gton CO_2eq up to 2100). It should be noted that this potential is based on the assumption of sustainable forestry.

Recently, IPCC's working group III concluded that there is medium confidence that carbon storage in wood products *together with material substitution* can contribute to climate change mitigation when considering sustainably managed forest ecosystems.

In terms of substitution, it very much depends which material is considered. Mineral construction products containing cement binders are considerable GHG emissions sources (constituting up to 5% of global CO_2 emissions) when the cement is assumed to be manufactured solely from calcination of carbonate rocks. However, in the use-phase, the natural reversal of this process - carbonation- provides a growing carbon sink. Carbonation of cement materials over their life cycle represents a large and growing net sink of CO_2, up to 0.3 – 0.8 Gton CO_2/yr. These carbonation sinks have so far not been considered in substitution scenarios, but can have significant impact. Further research is required to properly account for carbonation of cementitious construction products, but the potential sink of carbonation is up to par with (or higher than) the global potential sink of wood products.

Potential HWP sink of the EU

On average, the net carbon sink for HWP in Europe ranges between 31 and 40 Mton CO_2eq per year (an average of 35.5 Mton). This is for all HWP, not just for HWP in construction. This is based on assuming sustainable forestry (i.e. carbon neutrality) but without considering the GHG emissions for the production chain (which would decrease the potential size of the net carbon sink).

10.3 GHG emission reduction targets for the EU-27

Based on the Nationally Determined Contributions (NDCs) of the EU Member States, the overall reduction percentages of GHG emissions are known. In the time period 2021 – 2030, this results in the annual emission allocations for each Member State for each year of the period from 2021 to 2030 pursuant to Article 4 of Regulation (EU) 2018/842. Compared to the reference levels of 2005, the total GHG emission reduction target for the EU-27 up to 2030 amounts to 5.2 Gton CO_2eq. In order to arrive at a total GHG emission reduction target for the year 2050, a linear decrease in annual emission allocation is assumed for the period between 2030 and 2050. The total reduction percentage in 2050 is set at 95% (compared to the level in 2005).

By using this approach, the total GHG emission reduction target for the EU-27 amounts to 37.2 Gton CO_2eq. After the year 2050 up to 2100, emission reduction targets are assumed to be equal to the level of 2050 (i.e. assuming a near net carbon neutral EU-27 has been established). This means that starting in 2021 and up to 2100, the EU-27 would have a cumulative reduction target of 156,8 Gton CO_2eq relative to the year 2005.

10.4 The EU-27 HWP carbon sink in perspective of Climate change mitigation

In the previous paragraphs, the total net carbon sink of HWP and the total GHG emission reduction effort for the EU-27 were calculated. To put these in perspective in the potential of climate change mitigation, the relative contributions are provided here.

Relative contribution to EU-27 reduction target
The current net carbon sink of the HWP pool in the EU-27 amount to an average of 35,5 Mton CO_2eq/year (see section 10.2). Over the next 78 years (up to the year 2100), this equals to 2.77 Gton CO_2eq, or 1.8% of the total target for the EU-27 of 156.8 Gton CO_2eq up to 2100. Again, this is for the entire pool of HWP, not for HWP in construction.

Relative contribution to the global emission reduction effort
When looking at the remaining global GHG budget (within the 1,5 ºC scenario) of 500 Gton CO_2eq up to 2050, the global emission reduction effort amounts to 981 Gton CO_2eq. up to 2050, or 3481 Gton CO_2eq up to 2100. For the EU-27, this emission reduction effort is 156.8 Gton CO_2eq up to 2100, or 4.5% of the global effort.

The global potential of the HWP carbon sink equals to 29.2 Gton CO_2eq up to 2100, or 0.8% of the global emission reduction effort. The current potential of the EU-27 HWP carbon sink amounts to 2.77 Gton CO_2eq, which is 0.1 % of the global effort.

Relative contribution to global surface temperature
As part of the recent work on the relationship between the global surface temperature and cumulative GHG emissions, IPCC's Working Group I published its draft 6th Assessment Report. A near linear relationship between the cumulative CO_2 emissions and global warming for the five GHG reduction scenarios until the year 2050 was reported, as shown in Figure 6.

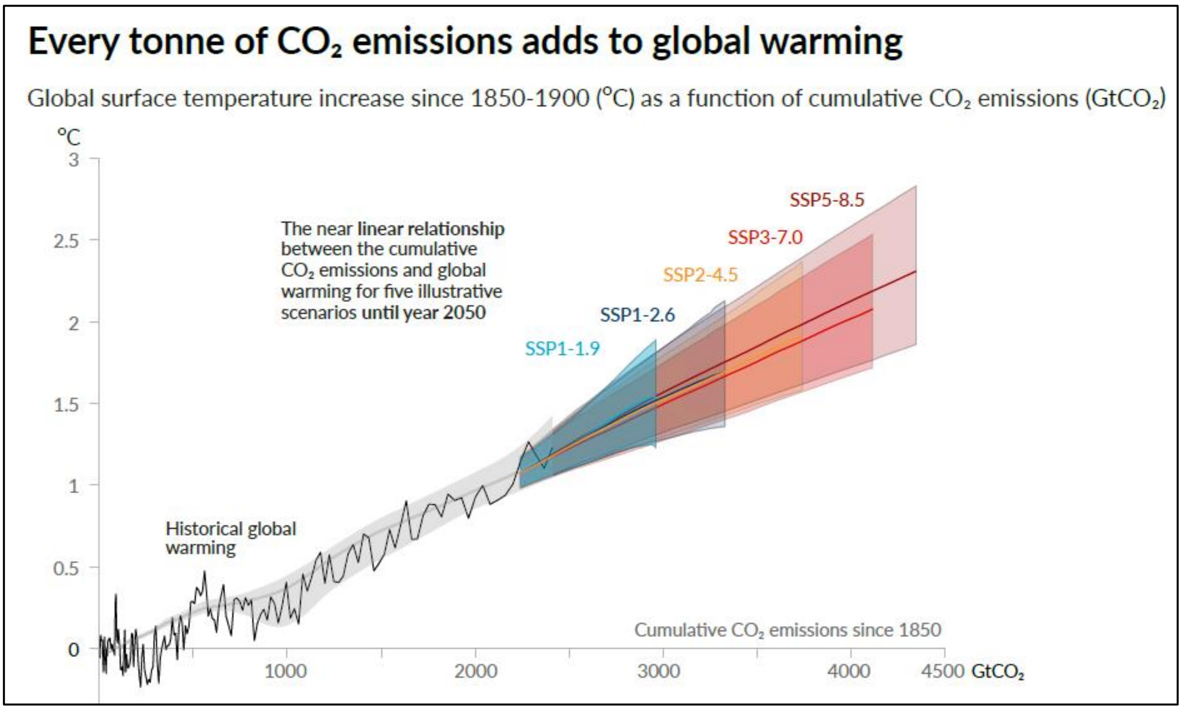


Figure 6
Near-linear relationship between cumulative CO_2 emissions and the increase in global surface temperature (Source: IPCC).

The slope of this curve was used to calculate the relative contribution of temporary carbon storage in HWP to mitigation of climate change expressed as ºC global warming reduction potential.

At the global level, assuming a cumulative size of the HWP carbon sink up to 2100 of 29.2 Gton CO_2eq, this would translate into a 0.02 ºC global warming reduction potential.

Overall, the total GHG emission reduction target of the EU-27 (156.8 Gton) would constitute a reduction of 0.09 ºC, whereas the current potential net carbon sink of the HWP pool in the EU-27 would amount to no more than 0.002 ºC.

10.5 Conclusions

The climate change mitigation potential of temporary carbon storage in the built environment has gained increasing attention. It is therefore a valid question what the climate change mitigation potential of harvested wood products (HWP) in construction can be.
The mitigation potential has been assessed by comparing the amount of carbon that can be stored in HWP in construction with the total GHG emission reduction effort at a global and European scale.

When assuming that all HWP in construction originated from sustainable forestry (i.e. carbon neutrality within the forest systems), which at the global scale certainly is a heavy assumption, and when considering all carbon storage in HWP to be permanent (which is not the case, then HWP in construction currently can contribute 0.8% to the GHG emission reduction effort when looking at the global scale, and 1.8% at the EU-27 scale. When looking at global warming reduction potential, these numbers translate into 0.02 and 0.002 ºC prevented warming respectively for HWP potential at the global and EU-27 scale.

The potential of HWP in construction is relatively low (0.8%) when considering that the total contribution of buildings to annual global GHG emissions is 21%. This underlines the need for all sectors to move forward on decarbonisation strategies.