Carbon Accounting for Building Materials

An assessment of Global Warming Potential of biobased construction products

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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

Kelvinbaan 40, 3439 MT Nieuwegein | PO Box 1475, 3430 BL Nieuwegein | The Netherlands

T +31 30 231 13 77 | E info@lbpsight.nl | www.lbpsight.nl

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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 (chapters 5-7).

2 The global carbon cycle

2.1 Carbon in the Earth system

In the Earth system, carbon is present or stored in the lithosphere (as carbonate rocks and fossil fuels), sediments (as organic matter or carbonates), ocean and freshwaters, soils and terrestrial biomass, and the atmosphere. The global carbon cycle consists of two parts, a slow cycle that involves the lithosphere (on geologic timescales, through plate tectonics and volcanism) and a faster cycle involving dynamic reservoirs (on more or less anthropogenic timescales, and through interaction with the biosphere).
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 2.1.

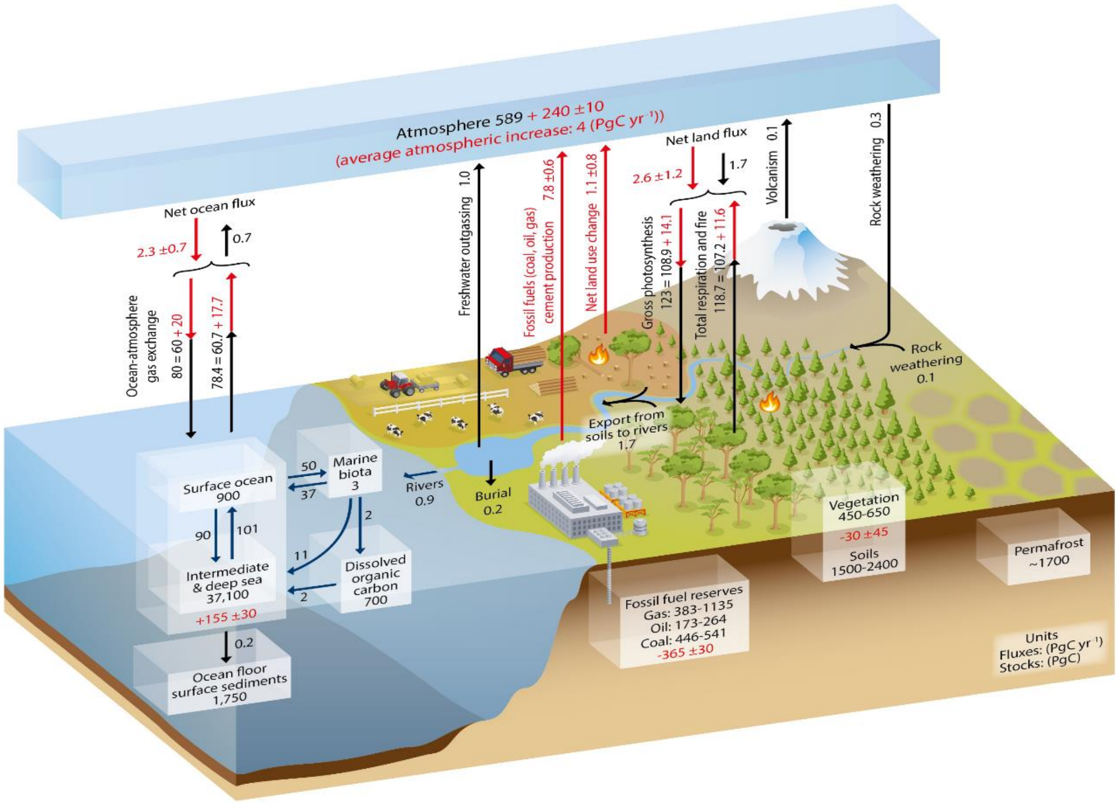

Figure 2.1
Graphic representation of the global carbon cycle (1)

In Figure 2.1, the boxed numbers represent reservoir mass or carbon sinks in petagrams of carbon (1 Pg C = 1 Gton C). Arrows represent annual exchange (fluxes) in Pg C per year (1). Black numbers and arrows represent preindustrial reservoir masses and fluxes, while red arrows and numbers show average annual anthropogenic fluxes for 2000 to 2009[2]. The red numbers in the reservoirs denote cumulative changes of anthropogenic carbon for the industrial period.

Oceanic sediments are thought to contain 4%, whereas ocean surface waters and the atmosphere each hold about 2% of the Earth system's carbon reservoirs. Oil, gas, and coal reserves are thought to contribute another 3%. Soils and permafrost hold 5% and 4% of global carbon, respectively, while carbon stored in vegetation adds about 1%.
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." Some of these carbon fluxes are sensitive to climate, and their resulting responses to climate change are known as "carbon cycle–climate feedbacks." A positive feedback can occur when carbon fluxes to the atmosphere increase as a result of, for example, increasing temperatures. More carbon in the atmosphere leads to further climate warming, possibly further increasing carbon fluxes to the atmosphere and so on. However, at the same time increased atmospheric CO_2 concentrations can also lead to increased carbon uptake by land and oceans (2).

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 also play a critical role in coupling the global carbon and energy (heat) cycles. There is high confidence that this ocean carbon–heat connection is one of the most important carbon–climate drivers, which is the transient climate response to cumulative CO_2 emissions (3)

The combustion of fossil fuels and land-use change for the period 1750–2019 resulted in the release of 700 ± 75 Gton C to the atmosphere, of which about 41% ± 11% remains in the atmosphere today. Of the total anthropogenic CO_2 emissions, the combustion of fossil fuels was responsible for about 64% ± 15%, growing to an 86% ± 14% contribution over the past 10 years. The remainder resulted from land-use change. During the last decade (2010–2019), average annual anthropogenic CO_2 emissions reached the highest levels in human history at 10.9 ± 0.9 Gton C yr-1. Of these emissions, 46% accumulated in the atmosphere, 23% was taken up by the ocean and 31% (3400 ± 900 Mton C per year) was removed by terrestrial ecosystems (4).

2 Based on the IPCC's 5th Assessment Report, WG1. These numbers are subject to change in the definitive version of the 6th Assessment Report, WG1

2.2 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. Under these circumstances 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 (5), where the net balance depends on the flux rate of CDR vs. that of release from the sinks.

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 (6), 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.

2.3 Terrestrial carbon storage

Within the scope of this study, terrestrial carbon storage pertains to the realm of harvested wood products. Viable forest-based storage methods include afforestation, reforestation, and forest management, through which terrestrial carbon storage is increased by enhancing net primary production (photosynthesis) and/or reducing GHG sources to the atmosphere (IPCC, nd). Although considered viable, these storage methods also have limits that may have adverse effects on the long-term terrestrial carbon sink (7).

Following the increasing awareness of potential risks to the permanence of carbon stocks of some types of forestation practices and the competition for land, there has been an increasing recognition that secondary forest regrowth and restoration of degraded forest and non-forest ecosystems can play a large role in carbon sequestration. This stems from the inherent characteristics of such ecosystems: high carbon stocks and rates of sequestration, higher resilience to disturbances, and enhanced biodiversity (8)(9)(10)(11).

According to the yet to be published 6th Assessment Report from Working Group III (IPCC), the global sequestration potential of forestation varies substantially depending on the scenario-assumptions of available land and of background climate. For example, afforestation of native grasslands, savannas, and open-canopy woodlands likely results in unwanted loss of ecosystems with rich biodiversity, carbon storage and other ecosystem services (12).

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3 Review of carbon neutrality principle

3.1 Introduction

All countries signing the Paris Agreement, under the United Nations Framework Convention on Climate Change (UNFCCC), have to create and execute a plan to decrease their greenhouse gas (GHG) emissions (13). A specific global 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 (14). 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, algae and fungi. 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 have to 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. When wood is used for long-lived wood products, carbon is effectively removed from the atmosphere, indirectly dampening the increase in global temperatures (15). It should be noted that this holds only true when assuming that the overall forest system these products are originate from show a net increase of their carbon sink.
Additionally, forestry is cost-effective, (16), while forest systems also provide other ecosystem services such as reduced land degradation, controlled hydrological processes and improved sustainable development (17).

With wood stated as a carbon neutral alternative to fossil fuel based products, the question arises whether wood products are truly carbon neutral, and in which cases the neutrality principle might not hold. In this chapter, the principle of carbon neutrality is reviewed on the basis of forest systems.

3.2 Carbon neutrality and forestry.

In principle, a natural, unmanaged forest systems are carbon neutral: over extended period of time, carbon emissions through degrading plant material and respiration equal carbon uptakes (sequestration) through photosynthesis. After all, all carbon that is sequestered in a tree is at some point in the tree’s life cycle released into the atmosphere again, or stored in the forest soil. Figure 3.1 demonstrates this principle.

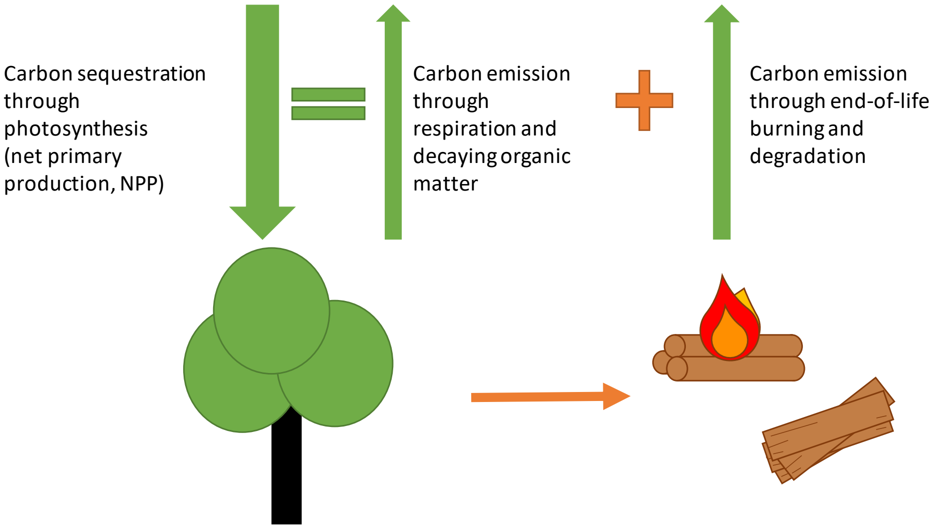

Figure 3.1
The carbon balance of the forest system without taking into account additional emissions from production processes and transport. Green vertical arrows represent biogenic carbon flows.

However, when wood is harvested a temporary carbon imbalance occurs, where more carbon is taken out of the system and is emitted to the atmosphere than is taken up by the remaining and regenerating forest in the same time span. The difference between the forest carbon stock prior to harvesting and afterwards is called the carbon debt (18). With sustainable forestry, this debt is only temporary: by planting new trees to replace the harvested ones, the lost carbon is slowly taken up again (Box 1). According to the IPCC, forestry is sustainable when the carbon stock in the forest remains at least equal throughout the entire management cycle (13). As most carbon is stored in the soil, preservation of soil carbon stocks during harvest is needed in order to have a stable carbon stock.

Concept and Definitions

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 carbon debt differs from a forest being a carbon source or carbon sink in the sense that it does not consider whether carbon uptake equals carbon emission at a specific point in time, but only considers how much the total forest carbon stock differs in a forest compared to the situation prior to harvest.

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 due to a trade-off between increased mortality and increased carbon uptake by older trees (19). 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** (20).

Consequently, if wood is used in place of a more carbon intensive material such as oil, plastic, 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.

Both the payback time and sequestration parity time depend on

1. the amount of carbon taken up by the regenerating forest in a specific time period;
2. the amount of carbon originally taken out of the forest by cutting;
3. the carbon emissions omitted through substitution of more carbon intensive materials with wood.

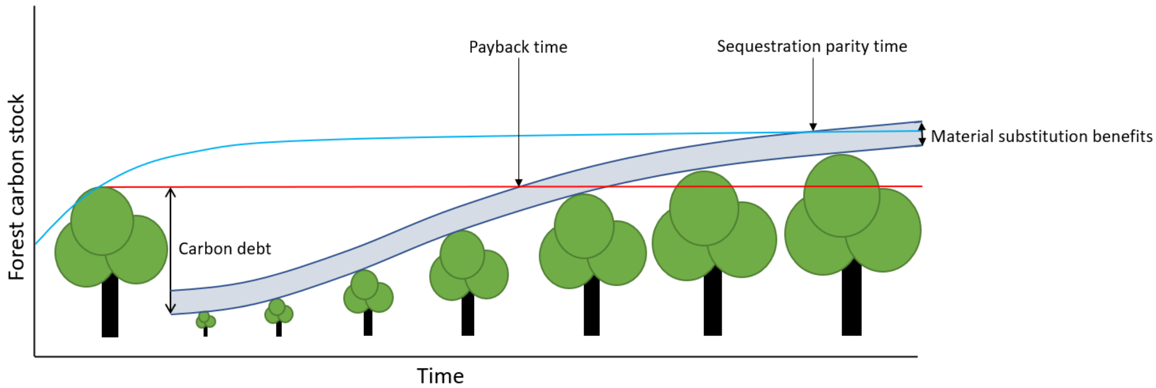

Figure 3.2 The difference between carbon debt repayment and carbon sequestration parity.

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.

The material substitution benefits are based on the difference between the carbon emissions from wood use and the carbon emissions from use of more carbon intensive materials such as traditionally produced steel or concrete. From a consequential point of view, the avoided carbon emissions through **material substitution** can 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, when determining whether a **product** is carbon neutral through life cycle analysis (**LCA**) these carbon omissions cannot be taken into account as the emissions from other materials do not influence the emissions from the product life cycle.

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 (21). Not taking into account avoided carbon emissions (omissions) through material substitution, the system cannot yet be carbon neutral, as emissions caused by transport and processing add to the natural emissions from the natural forest system itself and therefore exceed carbon sequestration levels. For this system to become carbon neutral, either the extra emissions need to disappear, e.g. through increasing the processing efficiency, or the sequestration needs to increase to compensate the extra emissions. This is demonstrated in Figure 3.3.

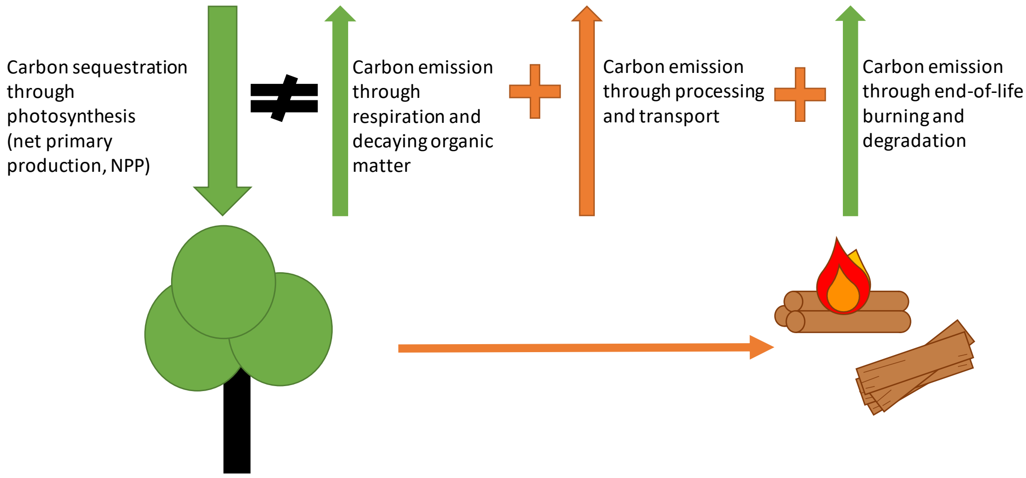

Figure 3.3
The woody biomass carbon balance when taking into account emissions from processing and transport. Green vertical arrows represent biogenic carbon flows.

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 degrading of the woody material (21). This concept is demonstrated in Figure 3.4. 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.

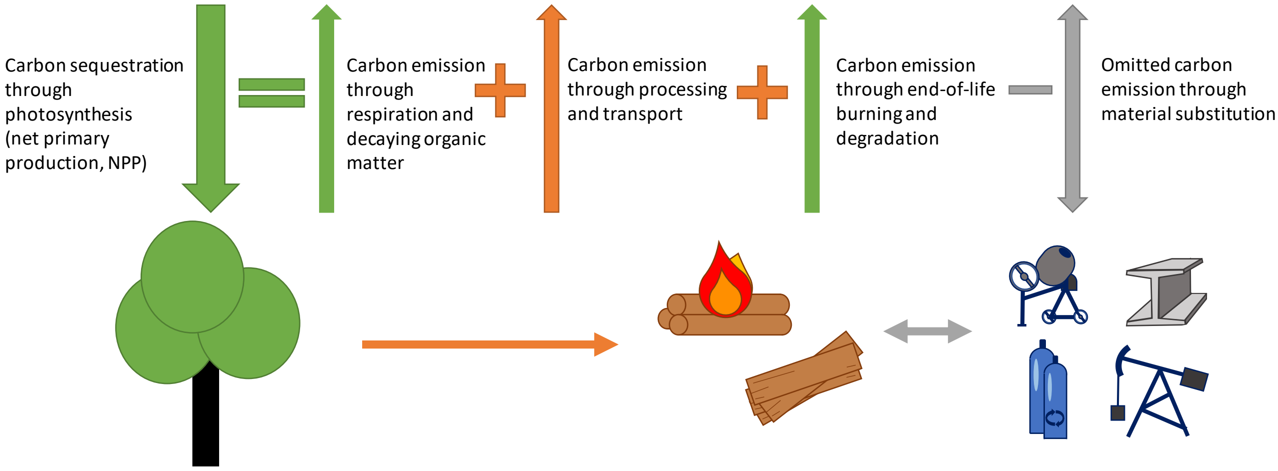

Figure 3.4
Summarizing the principle factors leading to carbon neutral wood production, including substitution of non-decarbonised materials. Green vertical arrows represent biogenic carbon flows.

Figure 3.4 shows the situation in which wood production can be carbon neutral: the carbon uptakes (left part of the equation) equal the carbon emissions minus the carbon omissions (right part of the equation). However, carbon sequestrations can also be higher than carbon emissions, e.g. by planting extra trees. In this case, the system is carbon negative: more carbon is taken up than is released to the atmosphere, which is positive for the climate. In the same way carbon sequestrations can be lower than the carbon emissions, which would make the system carbon positive: more carbon is released to the atmosphere than is taken up, which is negative for the climate.

Furthermore, if production of other materials becomes more efficient or maybe even carbon neutral, or if wood is used in place of less carbon intensive materials, wood production will not benefit from carbon omissions through material substitution and may not be carbon neutral.

3.3 Factors influencing the forest carbon balance

Within a forest system, several processes affect how (fast) trees are able to grow. This growth speed depends on the species and the availability of nutrients, water and light. Limitations in the availability of one of these factors impact the growth ability of the tree. In this way, the growth of an individual tree is also influenced by the growth of neighbouring trees, both in availability of these key needs and in protection against environmental factors such as wind. Trees grown at forest-edges have an adapted growth form through access to improved light supply and nutrient conditions (photomorphogenetic acclimation) and acclimatization to strong wind conditions (thigmomorphogenetic acclimation), which helps the trees to increase their root anchorage and structures. This adaptive advantage of edge trees disappears approximately three tree heights beyond the forest edge (22).

When harvest leads to gaps in the forest, new forest edges arise. This means that trees that before stood sheltered by other trees, now need to adapt to the new conditions. Removal of neighbouring trees increases the availability of light and nutrients for the remaining trees. However, the risk of windfall is also higher, impacting the production of the remaining forest (23)(24). This dynamic between individual trees in a forest system shows the need for consideration of carbon neutrality on a stand level, rather than per individual tree.

Since the carbon balance of a forest system is dependent both on the growth of each individual tree and the interactions between the trees, adverse management strategies and deforestation practices can turn the production forests into carbon sources, rather than carbon sinks. The same can be said for natural disturbances such as forest fires, storms and pest outbreaks. However, forest management both directly and indirectly impacts the risk on these natural disturbances, such as increased fire and wind risk when many old trees are left in the forest (25). For example, Norwegian spruce forests (wood which is used in the production of cross-laminated timber (CLT)) are more susceptible to wind damage than many deciduous species (24), making them more likely to turn into carbon sources as a result of this type of natural disturbance. However, natural logs in the forest also store carbon, and decompose at a slower pace than cuttings from harvesting left behind. An increased risk of pest outbreaks may also have adverse effects when the forest consists of only one species (26).

Furthermore, use of a clear-cut management strategy greatly increases the duration of the carbon debt of a forest system, as it can take several decades before the carbon uptake of the regenerating young forest equals the carbon emissions when clearcutting (27). As an example, Aguilos et al. (27) showed that it took a cool-temperate forest recovering from clearcutting 7 years to return from a carbon source to a carbon sink, and a further 8 to 34 years to balance the carbon debt left by the clearcutting. As the length of the payback time depends on many factors these numbers can differ between forest systems and even between rotation cycles.

Partial cutting, where individual trees are removed from the forest systems, reduces the duration of the carbon debt as less carbon is removed from the system. For example, Zhou et al. (28) showed that partial cutting had no significant effect on the carbon stocks on the forest floor, although aboveground biomass was reduced by approximately 40%. As most of the forest carbon is stored in the soil (29), see also Figure 3.5, use of partial cutting greatly decreases the carbon debt of the forest system that occurs as a result of the harvest, compared to clearcutting or other harvest types that include waste material removal and/or removal of the top soil layer.

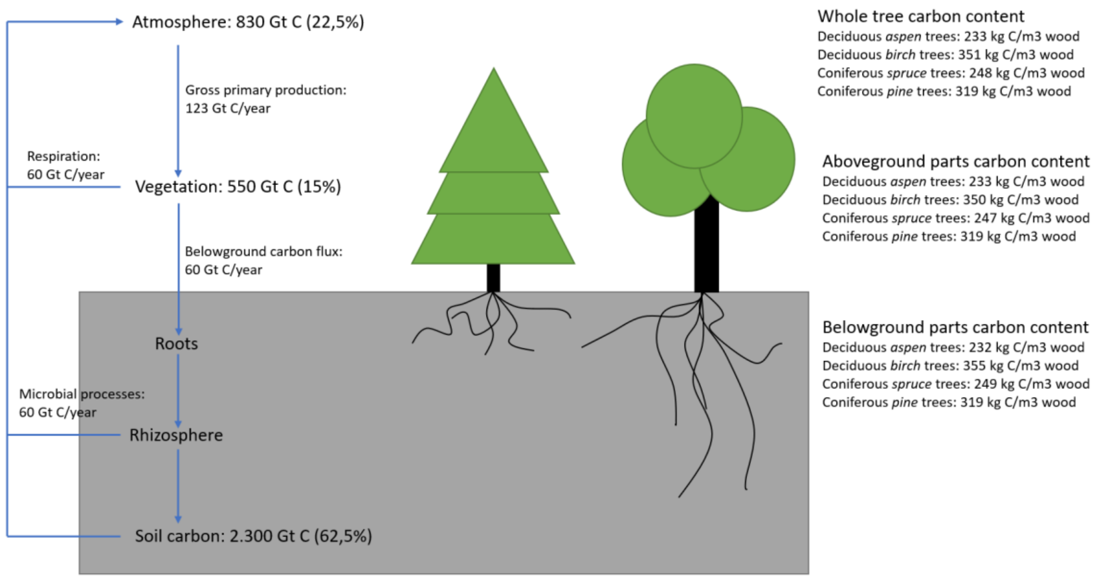

Figure 3.5
Showing the global forest carbon cycle, based on the work of Janowiak et al. (29) and the carbon content of the different tree parts of four tree species, based on the work of Bārdule et al. (30), corrected for the wood density of each species. It should be noted that ratio of carbon stored above and below ground differs greatly between different forest types.

Several studies show that removal of the material from the forest floor and removal of the top soil layer (the so-called "O horizon") greatly reduce the carbon content of the soil (31)(32). James et al. (31) differentiate between roughly 4 different harvest types on a tree level.

1. The tree is cut down, but only the stem is removed. In this case there is no significant difference in carbon content compared to the situation prior to harvest.
2. The tree is cut down, and the entire tree is removed from the forest system. This harvest type already removes 15% of the carbon content of the soil and forest floor.
3. The tree is cut down, but only the stem and parts of the waste material and O horizon are removed. This harvest type removes approximately 19% of the soil carbon content.

4. The most intensive harvest type is where the entire tree is removed, including full removal of waste material from the forest floor and removal of the O horizon. This harvest can result in a soil carbon content reduction of up to 25% (31).

The above percentages are averages. It should be noted that these differ between different forest types (different tree species and different climatic regions: temperate, boreal etc).

Recovery of the soil carbon content after harvesting can take several decades. The duration of this period again depends on many factors. For example, James and Harrison (33) show that recovery times depend on the soil type, with Spodosol and Ultisol soils recovering only after at least 75 years. Furthermore, carbon recovery time after harvesting depends on the regeneration method. For example, Rolls and Forster (34) show that if chosen for active replanting of trees after harvest, payback times are generally well within a century. However, if chosen for natural regrowth, payback times for both forest carbon and soil carbon can take more than a century.

As can be expected, deforestation (where no trees are planted to replace the removed trees) also greatly increases the global forest carbon debt. For example, a recent study by Harris et al. (35) shows that although global forests currently still function as a net carbon sink, with carbon removals double the amount of carbon emissions, deforestation greatly impacts this functioning. Currently deforestation is highest in tropical regions. As tropical forests represent approximately half of the world's carbon sink (36), continued deforestation in these regions will greatly impact the ability of global forests to act as carbon sinks.

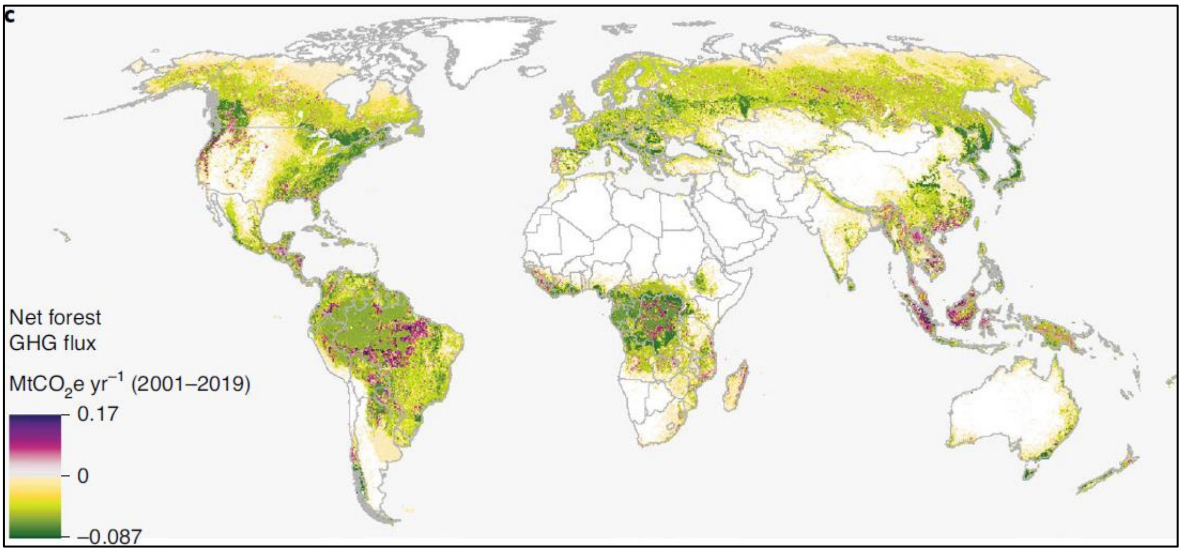

Figure 3.6
From Harris et al. 2021: the net carbon fluxes throughout the globe.

These findings are confirmed by the recent publication of the draft sixth assessment report of working group III of the IPCC (37). The global forest area in 2020 is estimated at 4.1 billion ha, representing 31% of the total land area. A significant share (54%) of the world's forest area concerns five countries – the Russian Federation, Brazil, Canada, the USA and China. Forest loss rates differ among regions though the global trend is towards a net forest loss. The global forest area declined by about 178 Mha in the 30 years from 1990 to 2020. The rate of net forest loss has decreased since 1990, as a result of reduced deforestation in some countries and forest gains in others (37).

In the fifth assessment report of working group III of the IPCC (13) four mitigation options on the supply side are mentioned that could improve the ability of production forests to act as carbon sinks:

1. Reducing deforestation. By reducing deforestation and controlling other anthropogenic disturbances such as fire and pest outbreaks, existing carbon pools in forest vegetation can be maintained.
2. Afforestation/reforestation. By planting trees on non-forested agricultural lands, new and larger forest sink carbon pools can be created.
3. Forest management. Management influences the ability of a forest system to sequester carbon from the atmosphere. Several management strategies are available that increase this carbon sequestration, such as extended rotation cycles, reduced damage to remaining trees, reduced logging waste, implemented soil conservation processes, fertilization, sustainable extortion of wood energy and improved wood use efficiency.
4. Forest restoration. Secondary forests and degraded forests can have biomass and soil carbon densities that are less than their maximum value. Allowing these systems to regenerate increases their carbon sequestration.

However, increased afforestation and change of management practices can also increase the overall carbon emissions of the forestry sector. Land-use change can result in net carbon emissions through transformation processes and changes in the soil type and vegetation. Furthermore, forest expansion onto former agricultural can increase the soil carbon sink, as soil carbon content of forests is usually higher than that of agricultural land, but may lead to more intensive farming practices with higher emissions elsewhere, as well as possible increased imports of agricultural products (38). Although coniferous species grow faster and therefore take up more carbon than deciduous trees, conversion from natural deciduous forests to managed coniferous forests has increased Europe's carbon debt over the last few centuries, as the carbon stock in soil, woody debris and living biomass is 6-43% lower in managed forests than in unmanaged forests (39).

Nabuurs et al. (18) reinforce this principle, by stating that carbon stock build-up is lower in managed forests than in natural forests, although both function as net carbon sinks. They attribute this difference to the slower growth rates of very young forests compared to semi mature forests and the fact that during decomposition of remaining harvest waste material only part of the carbon ends up in the soil, with the remainder emitted to the atmosphere. However, the authors also state that Europe's forests show no remaining carbon debt with increased wood demand, but only a very long parity effect, as eventually fossil carbon will be replaced by wood, gradually solving the remaining carbon debt (18), assuming sufficient land is available.

Although afforestation can result in net increases in carbon sequestration, Bastin et al. (40) show that limited land is available for afforestation or reforestation. The authors state that several countries have even set reforestation goals higher than is spatially possible, showing the restrictions in this mitigation method. Furthermore, globally, the forest cover area is expected to decline.

In Figure 3.7 potential tree cover is determined on grid cells of approximately 3.000 m2. Grey grid cells show areas not available for reforestation due to adverse environmental conditions and other uses. White grid cells represent areas where very limited area is available for reforestation (<1%), e.g. due to the majority of the grid cell being used by agricultural or urban areas, or having adverse environmental conditions.

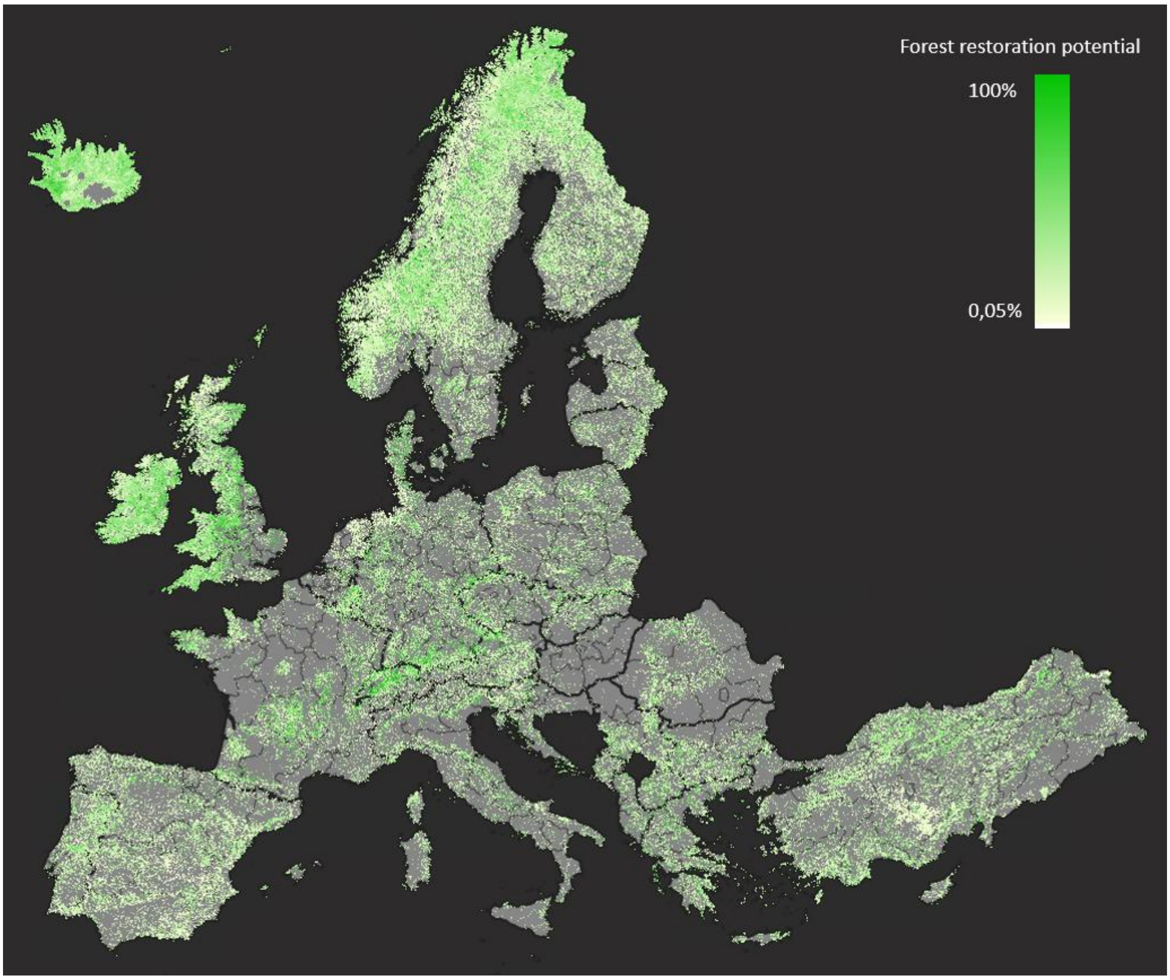

Figure 3.7
Area available for reforestation after subtraction of the areas used as existing forests, agricultural land and urban areas. Data source: Bastin et al. (40).

Additionally, management practices chosen to protect the forest against damage, such as closed felling and small-area felling (partial felling whereby forest gaps left after tree removal cannot exceed 2.000 m^2 or hold less than 15 trees) (41), can cause increased carbon emissions through increased harvesting effort, possibly negating the positive effects of the management strategy.

In Europe, approximately 80% of the felled material is removed from the forest (Figure 3.8: 224 Mton/yr out of 281 Mton/yr). The remaining 20% is left in the forest system to degrade naturally. From Figure 3.9 it is deduced that of this removed material, 23,4% is processed into long(er)-lived biobased products (105 Mm^3 sawnwood + 49 Mm^3 panel industry = 154 Mm^3 out of a total of 658 Mm^3 roundwood). This shows that only 18,7% (23,4% of 80%) of the felled material actually ends up in longer term purposes. The remaining amount is used for short term purposes, such as pulp and paper production, and energy generation.

Figure 3.9 shows that 12,3% of the wood removals is used for pulp and paper (81 Mm^3 out of a total of 658 Mm^3 roundwood) , and 62,8% is used in the production of bioenergy, either directly, or indirectly through waste materials from wood processing by-products (278 Mm^3 directly + 135 Mm^3 from by-products = 413 Mm^3 out of a total of 658 Mm^3 roundwood. It should be noted that the flow from the pulp industry through the by-products towards bioenergy in the diagram represents the creation of black liquor, from which salts can be extracted. Furthermore, the numbers for wood use in bioenergy generation include woody materials from the fellings that cannot be used in another way, such as bark.

Approximately 14% of the removed wood is exported to non-EU countries in various stages of the production process, increasing emissions from transport (42)(48).

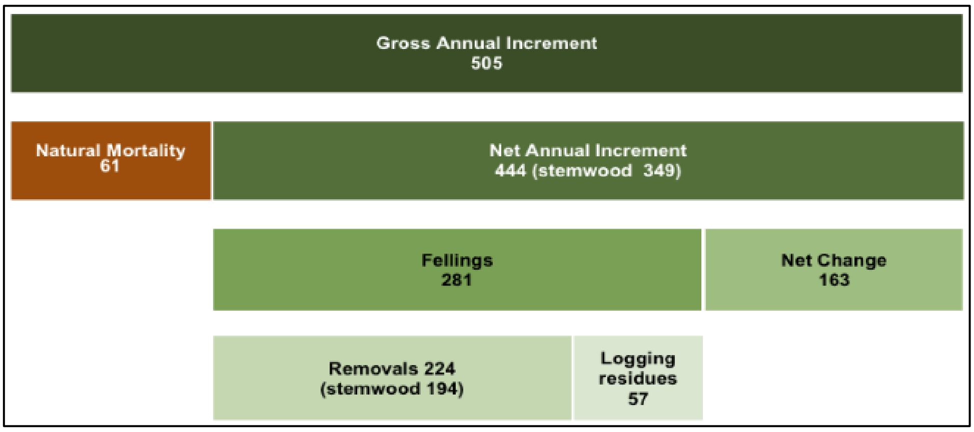

Figure 3.8
Indication of the increment, fellings and removals in EU-28 forest area available for wood supply; average values in Mton/yr for the period 2004-2013 (42). It should be noted that these numbers are subject to high uncertainty, especially concerning the harvest levels and removals of woody biomass from EU forests.

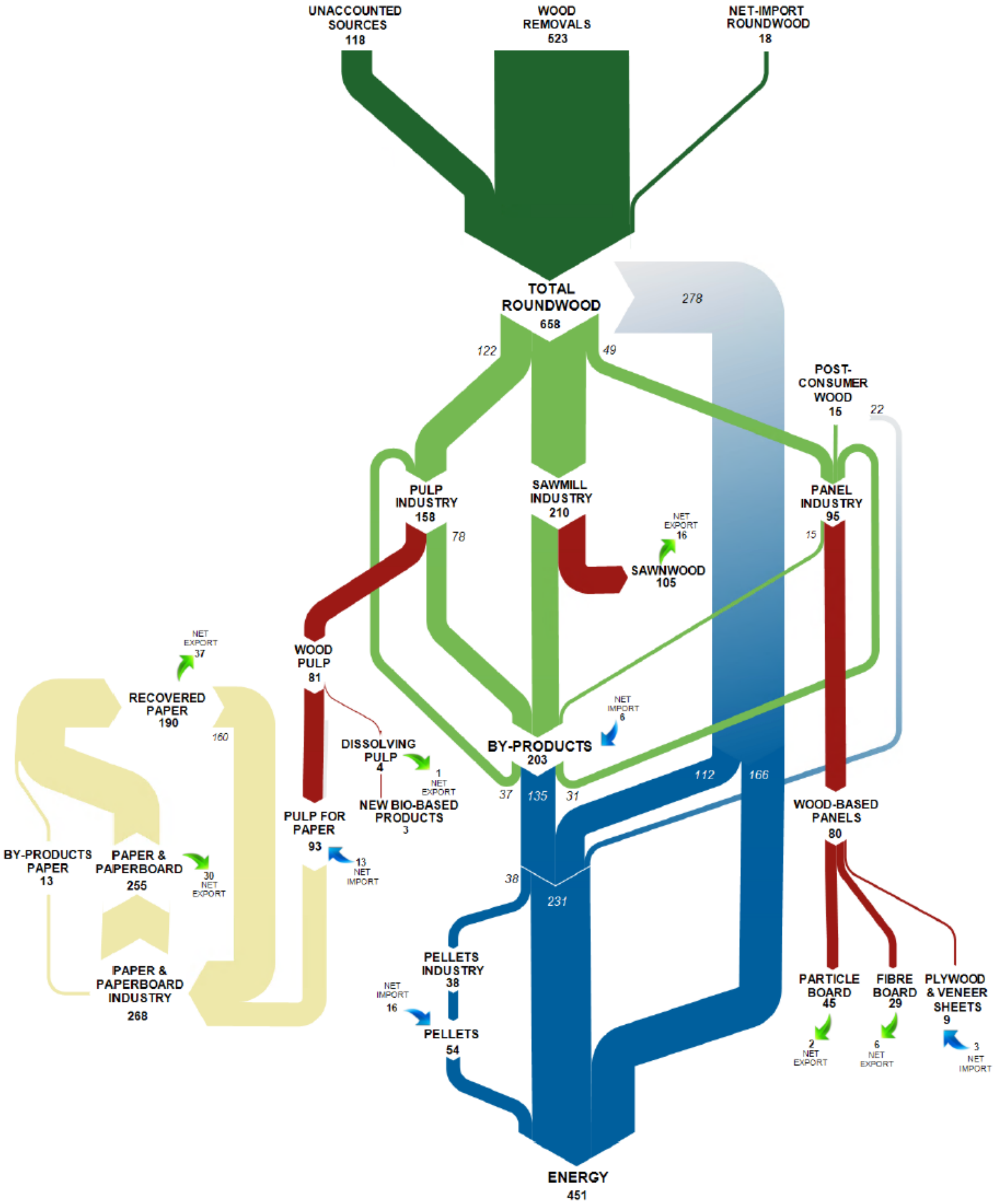

Figure 3.9

European Commission (47): The Sankey diagram of roundwood sources and downstream uses for the year 2015 ([Unit: Mm^3 SWE under bark]

The IPCC (13) also gives several demand-side options for reducing the carbon emissions of the forestry sector. By conserving wood products through more efficient use and replacement with recycled materials, carbon emissions can be significantly reduced. Furthermore, substituting non-renewable sources such as traditionally produced aluminium, steel or concrete with wood can also cause a net reduction of carbon emissions.

However, the highest greenhouse gas benefits can be reached by optimization of carbon stocks in forests and in long-lived products, as well as by using by-products and wastes for products and bioenergy production, rather than carbon stock directly from the forest (which in a large part is the current practice as shown by Figure 3.9).

3.4 When is forestry and production of biobased materials not carbon neutral?

If so many different factors influence whether a biobased product is truly carbon neutral, then the follow-up question is: Under what conditions does carbon neutrality not apply? As described before, a forest system can be either carbon positive, carbon neutral, or carbon negative, depending on the balance between emission, sequestration and omission processes. It then follows that in the following cases wood products are not carbon neutral:

- Products from forests without tree replacement. When trees are harvested and no or fewer new trees are planted to replace the forest, carbon emissions exceed carbon sequestrations and omissions, and the carbon debt left after cutting cannot be balanced. Several studies have shown the negative effects of deforestation, such as Kruid et al. (43) and Harris et al. (35). It should be noted that natural regrowth still counts as replacement of removed trees, as eventually the forest will be replaced. However, if natural growth leads to a decrease in number and/or size of the trees in a forest stand, then the carbon debt will not be balanced.
- Products with high emissions from transport. If wood is transported over great distances or with highly polluting transportation methods, overall emissions may exceed sequestrations and omissions.
- Products with high emissions from processing. In the same way as with transport, if wood is processed with highly polluting methods, overall emissions will exceed sequestrations and omissions.
- Products substituting low emission products. If wood is used to replace lower emission products, then no carbon will be omitted, and emissions will exceed sequestration. This can occur when wood is used as an alternative energy source to non-carbon sources such as wind, solar, geothermal and hydropower (44), or when replacing alternative building materials such as concrete and steel that are made with low emission processes, for example electrolysis in steel production. These methods also require less land area, leaving more area for other uses, such as conservation forests and agriculture.
- Products made from production forests that have replaced conserved native forests. Keith et al. showed (44) that although wood has many benefits as a construction material, conservation of

woody biomass by native forest conservation is much more effective in climate mitigation than exploiting the forests for the production of biobased construction materials. They attribute this effect to the longevity of the carbon storage. Only a small proportion of harvested wood products is transferred to carbon pools with high longevities, while the majority of the carbon stocks in forest biomass have high longevity. Furthermore, harvest leads to net emissions through processing and transport, where conservation forests generally have a net carbon uptake.

- When harvest and emission rates exceed regeneration times. If emission rates caused by end-of-life processes and bioenergy production exceed sequestration rates in regenerating forests, the total carbon debt of the global forests will steadily increase.

By estimating the CO_2 emissions and removals from the harvested wood products (HWP) pool using the IPCC KP Tier 2 method, Pilli et al. (45) show that the carbon sink in Europe's HWP is slowly saturating. They explain this phenomenon by stating that in a constant harvest scenario, the domestic production of wood products (and the consequent inflow of carbon into the HWP pool) stabilizes.

Consequently, the inflow of carbon to the HWP pool by domestic production will eventually equal the outflow of carbon from the HWP pool by end-of-life processes. This indicates that increases in the carbon pool of HWP can only occur with increased harvest rates, as the carbon inflow needs to exceed the carbon outflow. However, increasing harvest rates will decrease the carbon sink in the forest system, minimizing the overall carbon sink potential. Furthermore, there is a limit to how much wood can be harvested. It should be noted that another way of increasing the amount of carbon in the HWP pool is to reduce the outflow, i.e. by implementing circular economy principles on suitable HWP construction products.

Tsunetsugu and Tonosaki (46) state that the carbon stock change due to the implementation of harvested wood products in Japan can be considered as a large emission, as the domestic inflow of carbon into the HWP pool is much smaller than the outflow by end-of-life processes from both domestic and imported products. In other words, the outflow of domestically used wood as waste is greater than the inflow of wood for use. This imbalance between inflow and outflow will eventually stabilize, when there is no more excess in HWP at the end of their life-cycle.

3.5 Conclusions

These studies combined with the long payback and parity times related to forestry show the importance of the temporal aspect of the carbon balance in HWP. In the long term wood substitution of fossil carbon based products can be beneficial, if carbon uptake outnumbers emissions from forestry, the harvested wood is used in long-lived products 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, especially when deforestation cannot be prevented. In that sense, it would be better to let existing forests grow and focus on restoration, afforestation and reforestation.
Increased efficiency and sustainability in the current production processes of other materials[3] such as aluminium, steel and concrete potentially have greater impact because these entail a larger volume worldwide.

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).

3 Altought increased sustainability of the production chain of forestry-based products can be expected as well.

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4 Assessment of IPCC and EU Greenhouse Gas Roadmaps

4.1 Assessment on IPCC global climate targets

4.1.1 Introduction

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 (49). These assessments are made by three working groups, each with its own focus.

The first working group (WGI) studies the physical science of past, present and future climate change. This includes temperature changes, hydrological cycle and changing precipitation patterns, extreme weather, glaciers and ice sheets, oceans and sea level, biogeochemistry and the carbon cycle, and climate sensitivity (50). The second working group (WGII) investigates the impacts of climate change. This includes impacts on ecosystems and biodiversity, and human societies, cultures and settlements, both regional and worldwide (52). The third working group (WGIII) is involved in climate change mitigation. In other words, preventing or at least limiting greenhouse gas (GHG) emissions and enhancing activities that remove the GHGs from the atmosphere (53).

4.1.2 Representative Concentration Pathways and Shared Socioeconomic Pathways

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 (54). 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. Additionally, they include both high- CO_2 emission pathways without climate change mitigation and low- CO_2 emissions pathways (55). It should be noted that this report is still subject to final editing.

Both the RCPs and the SSPs form different scenarios based on radiative forcing and GHG emissions reported in literature. However, SSPs include a broader range in radiative forcing scenarios (IPCC, 2021). The RCPs include a mitigation scenario (RCP 2.6), two intermediate scenarios (RCP 4.5 and RCP 6.0) and one scenario with very high GHG emissions (RCP 8.5). The land-use scenarios included in the RCPs show a range of possible futures, ranging from deforestation to net reforestation, consistent with prevalent literature (56). The SSPs include one low emissions pathway (SSP1-1.9), two intermediate scenarios (SSP1-2.6 and SSP2-4.5 and) and two high emissions pathways (SSP3-7.0 and SSP5-8.5) (55). Both RCPs and SSPs are labelled by the level of radiative forcing they reach in 2100. However, the ratios of gasses that constitute GHG differ between the two types of scenarios. Therefore, they are not directly comparable. Radiative forcing is the difference between incoming and outgoing solar energy of the earth, given in W/m^2 (55)(56).

RCP 2.6 assumes that radiative forcing peaks at 2,6 W/m^2 and declines before 2100. Within this scenario global warming likely stays within 1,7 degrees Celsius by the year 2100, compared to 1870. Sea level rise will likely be limited to 0,55 meters. Most models indicate that in order to meet the RCP 2.6 radiative forcing, drastic climate action needs to be taken to reach a substantial net uptake of on average 2 GtCO_2/yr. (56). SSP1-1.9 leads to warming of below 1,5 degrees Celsius in 2100, with limited temperature overshoot in the period after 2100. The scenario assumes that emissions will reach net zero around mid-century (55).

RCP 4.5 represents a scenario where radiative forcing stabilizes at 4,5 W/m^2 after 2100. In RCP 6.0 radiative forcing will exceed 6,0 W/m^2 after 2100. In these scenarios global warming will likely remain lower than respectively 2,6 and 3,1 degrees Celsius by the year 2100, compared to 1870. Sea level rise will likely be limited to 0,63 meters in both scenarios (56). SSP1-2.6 and SSP2-4.5 represent scenarios with stronger climate change mitigation measures and therefore lower emissions than the high CO_2 emission scenarios, but are not as effective in limiting global warming as the low-emission scenario SSP1-1.9. SSP1-2.6 was designed to model a warming limited to below 2 degrees Celsius. SSP2-2.6 limits warming to approximately 2.7 degrees Celsius (55).

RCP 8.5 is the most pessimistic scenario, which assumes that radiative forcing exceeds 8.5 W/m^2 by 2100. This scenario represents a sort of business as usual scenario where no measures are taken to limit GHG emissions. In this scenario global warming will reach approximately 4,8 degrees Celsius by the year 2100, compared to 1870. This would result in a sea level rise that will likely be limited to 0,82 meters (56). SSP3-7.0 has overall lower GHG emissions than SSP5-8.5, which assumes no mitigation measures are taken, but CO_2 emissions still almost double by 2100 compared to 2021 levels. SSP3-7.0 shows that global warming will reach approximately 3,5 degrees Celsius compared to pre-industrial levels. This is almost 4,5 degrees Celsius for SSP5-8.5 (55).

4.1.3 Global warming effects and risks

In all RCPs and SSPs, precipitation patterns, snow cover and sea-ice, oceanic effects and intensity and frequency of extreme weather events will change (55)(56). The net effects of these changes can differ between regions. For example, high latitudes and mid-latitude wet regions can probably expect increases in annual mean precipitation, whereas many mid-latitude and subtropical dry regions can expect decreases in annual mean precipitation. The main effects per region are summarized in Figure 4.1 (56). As can be seen, European countries can mainly expect increased flood damage, water restrictions and damages from extreme heat events and wildfire.

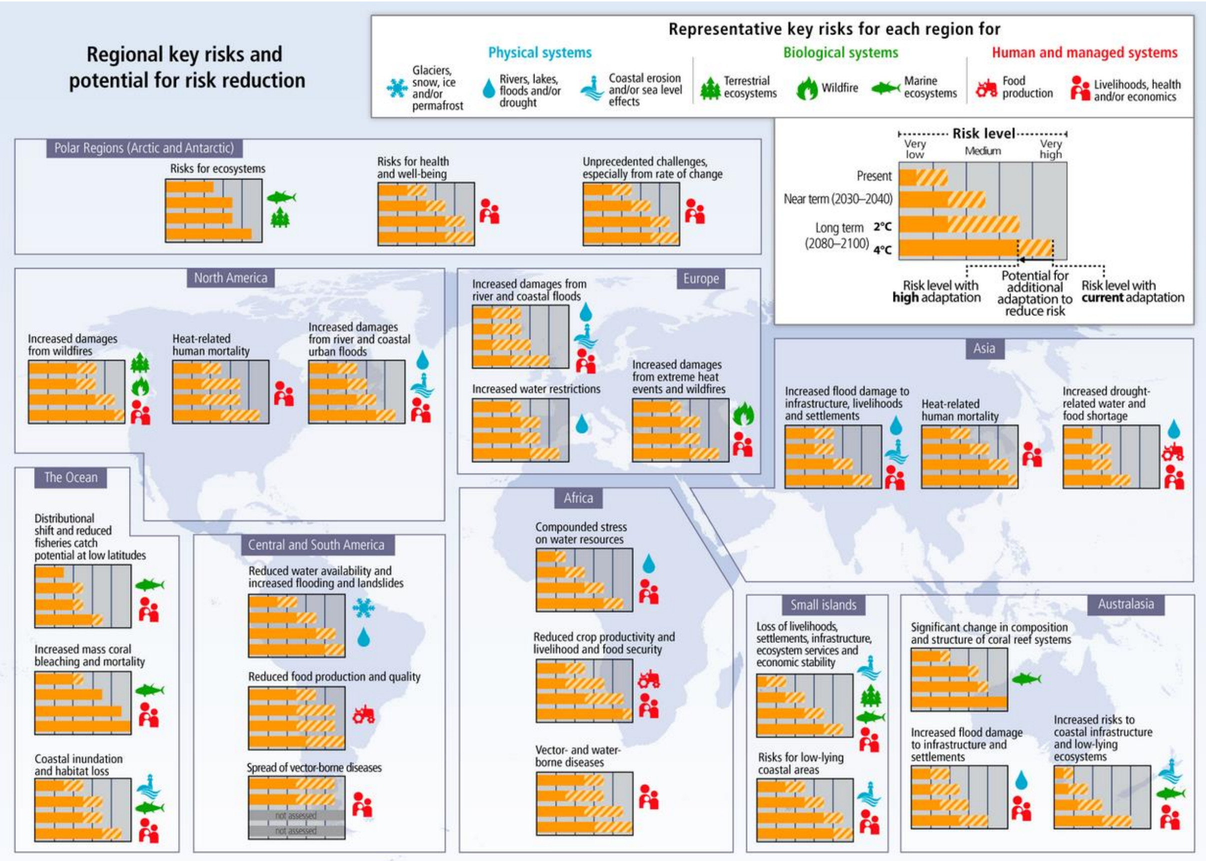

Figure 4.1
Summarizing the regional effects of a changing climate. Source: IPCC (56).

The IPCC has identified four main risks that span sectors and regions:

- Severe risks of ill-health and disrupted livelihoods as a result from sea level rise, storm surges, coastal flooding, inland flooding in some urban regions and periods of extreme heat.
- Systemic risks of break-down of infrastructure networks and critical services due to extreme weather events.
- Risks of flood and water insecurity, loss of rural livelihoods and loss of income. Particularly for poorer populations.
- Risks of loss of ecosystems, biodiversity and ecosystem services, goods and functions.

The higher global temperatures become, the worse the effects. For example, although all RCPs lead to increased intensity and frequency of extreme weather events, the difference between average precipitation changes in RCP 2.6 and RCP 8.5 can be up to 40%. This same effect can be seen in Northern Hemisphere spring snow cover, where RCP 2.6 leads to a reduction by approximately 7%, whereas RCP 8.5 increases this reduction to 25%. As can be seen in Figure 4.1, the extent of these risks can be reduced by limiting the rate and magnitude of climate change.

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 (57).

4.1.4 Global warming of 1,5 degrees Celsius

In order to better understand the impacts of global warming of 1,5 degrees Celsius and to help countries find ways to reach this target, the IPCC has created a special report 58). Within this report it is stated that at the current rate, global warming is likely to reach the 1,5 degrees Celsius mark by 2050. Further warming depends on the cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions. Due to climate feedbacks, on a longer time scale more effort is probably needed to prevent global temperatures and sea levels from rising further (58).

Global mean sea level rise is projected to be approximately 0,1 meters higher with global warming of 2 degrees Celsius than with global warming of 1,5 degrees Celsius. Future emission pathways determine the speed and magnitude of sea level rise. A slower rate enables better adaptation of both human and ecological systems, such as coastal and delta systems. Furthermore, warming of 1,5 degrees Celsius brings severe and widespread risks for ecological systems, coastal floods and extreme weather events. However, a 2 degrees Celsius warming makes several of these hazards irreversible. Unique and threatened ecosystems around the world will likely disappear or will be severely affected. The IPCC has determined five reasons for concern (RFCs) and has indicated the risks of these with different global temperature changes (58). These are summarized in Figure 4.2.

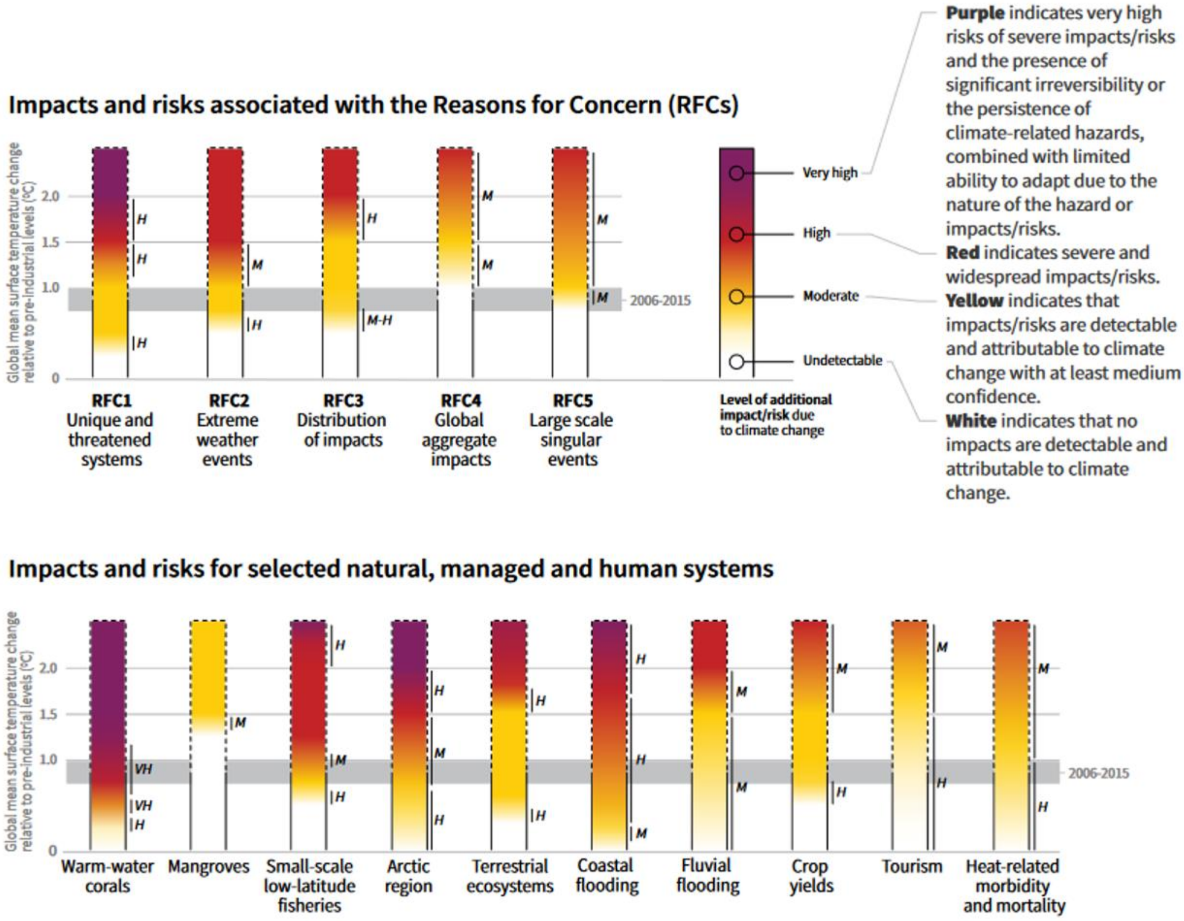

Figure 4.2
Summarizing the risks associated with global warming of 0-2,5 degrees Celsius. Source: IPCC (58).

In order to reach the 1,5 degrees Celsius warming target, global net anthropogenic CO_2 emissions have to decline by about 45% in 2030 compared to 2010, reaching net zero around 2050. For a 2 degrees Celsius warming, this would change to a reduction of 25% by 2030 and net zero by 2070. Non- CO_2 GHG emissions should show deep reductions with equal magnitude for both targets (58).

4.1.5 Potential contribution of forestry to global climate targets

As stated, the IPCC does not set global climate targets themselves, but their assessment reports provide a scientific basis for policy makers. As such, they can be used to (help) make policy decisions at the national (or European) level.
In the recently published IPCC draft assessment report (59), several mitigation options were assessed, among others for AFOLU (agriculture, forestry and other land use) and buildings. Of these options, forest conservation, ecosystem restoration, afforestation and reforestation have a potential GHG emission reduction of approximately 7 Gton CO_2eq/yr., whereas improved sustainable forest management combined with enhanced use of wood products in construction show potential for a reduction of approximately 2 Gton CO_2eq/yr. (see Figure 4.3). In other words, it is better to let

forests continue to grow and restore, than harvest them (even if done sustainably) for use in buildings, especially when they are older forests (59)(60). In that sense, it is worth investigating the EU (national) GHG and forestry roadmaps to assess how these mitigation options have been considered and/or formalised. This is reported in section 4.2.

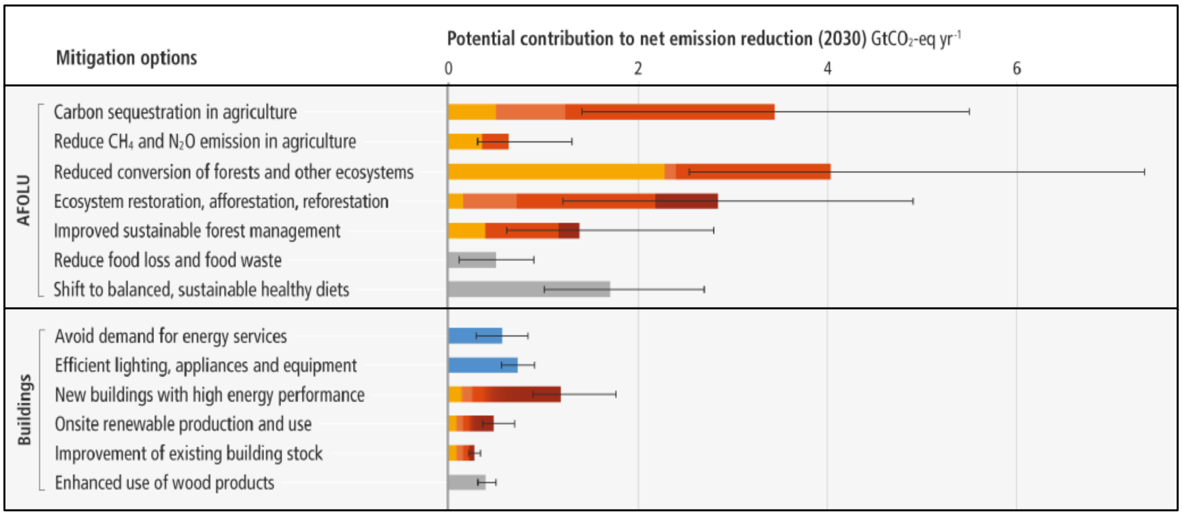

Figure 4.3
Potential contribution to net emission reduction of several mitigation options in AFOLU and buildings. Adopted from IPCC, 2022, Figure SPM.7 (59)

4.2 Assessment of main national GHG roadmaps

4.2.1 Introduction

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

The ministries responsible for the forestry strategy of each of these member states were contacted for additional information. Two of these ministries, namely those from Spain and Germany, responded to the query so far.

4.2.2 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 4.4 (61).

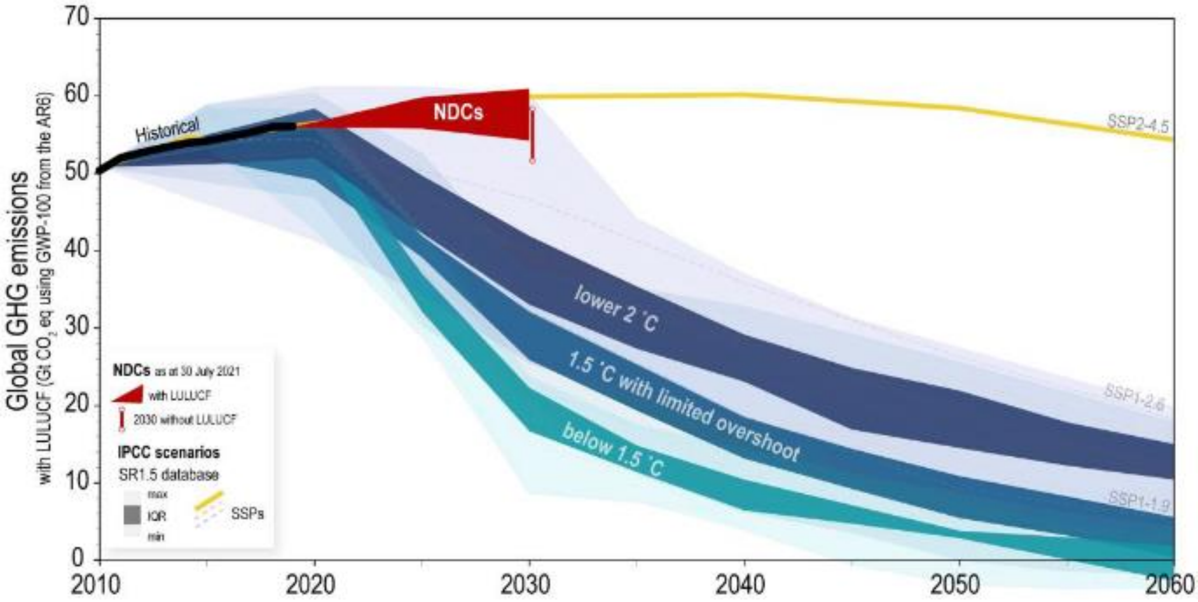

Figure 4.4
Summarizing global GHG emissions as needed to reach the 1,5 and 2 degrees Celsius warming targets, and the GHG emissions resulting from the policies set out in the NDCs. Source: UNFCCC, (61).

4.2.3 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.

These targets differ between countries, with Czech Republic even being allowed to increase emissions until 2020 (62) and Bulgaria setting its reduction target at 0% for 2030 (63). Additionally, some countries have chosen to compare their 2030 and 2050 levels to those in 1990, making comparisons between the member state targets difficult. However, with a few exceptions, all EU member states have set their 2050 reduction targets at either climate or carbon neutrality.

In addition to the Effort Sharing Legislation, in 2018 the "Regulation on the governance of the energy union and climate action (EU) 2018/1999" (64) 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 (65).

Figure 4.5 shows the greenhouse gas (GHG) reduction targets of all 27 member states as mentioned in their National Energy and Climate Plans (NECPs). Noticeable is that countries with low emission targets for 2030, such as Bulgaria and Poland, do not necessarily also have low emission targets for 2050. In the same way, some countries with high reduction targets for 2030, like Estonia, Sweden and Finland, have set relatively low reduction targets for 2050.

Within the NECP the countries state their targets and measures regarding the following five dimensions (European Commission n.d.):

- Energy efficiency;
- Renewables;
- Greenhouse gas emission reductions;
- Interconnections;
- Research and innovation.

NECPs cover these aforementioned dimensions in several sectors, including building, agriculture and forestry. 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 (51).

Since no concrete climate roadmaps were available for any of the 27 EU member states, the following section only focuses on their forestry policies.

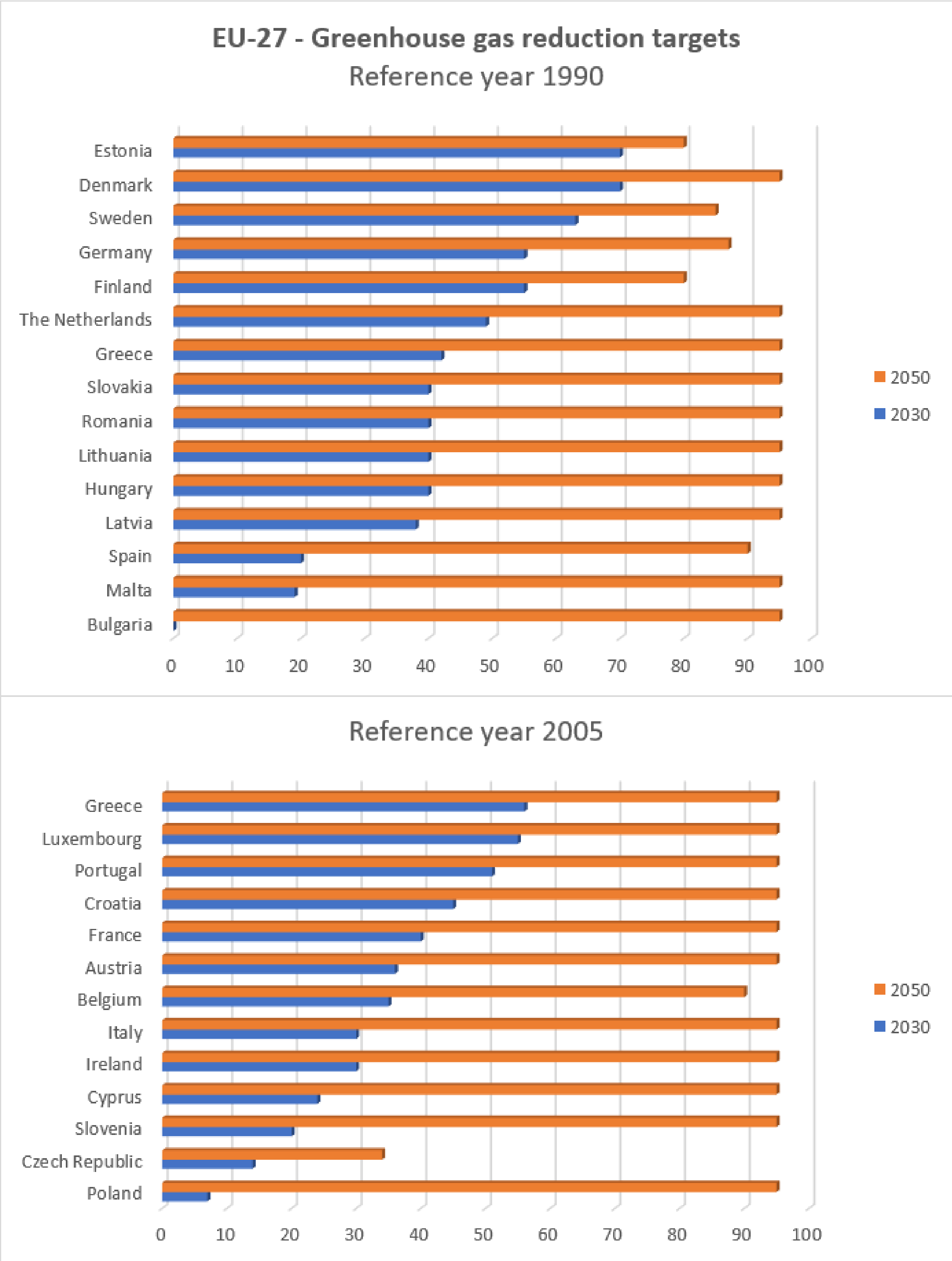

Figure 4.5

National climate targets. Sources: National Energy and Climate Plans (65)

4.2.4 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.

4.2.4.1 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 (66), see Figure 4.6.

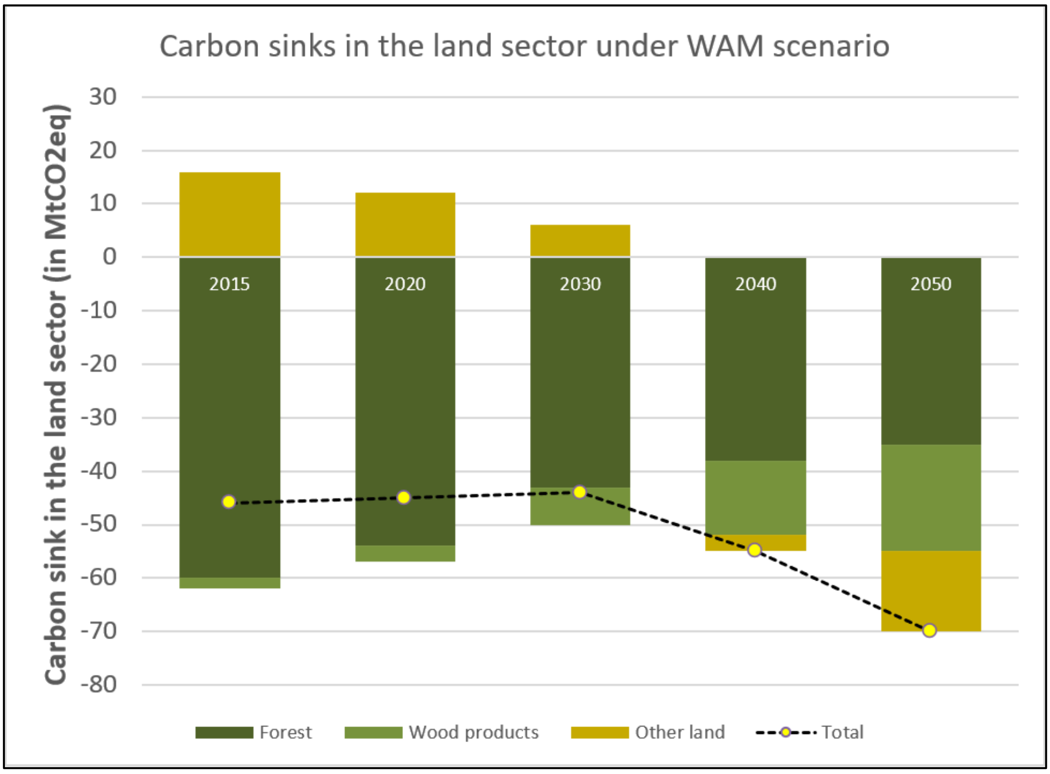

Figure 4.6

Carbon sink targets for France as included in their NECP. Source: Ministry of the Ecological Transition (66)

4.2.4.2 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. The accounting rules stated in the same regulation differ between land categories. 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.

To guarantee achievement of the target at the EU level, all member states must produce compliance reports for the periods 2021-2025 and 2026-2030. These reports should contain the total balance of emissions and removals and the states' possible use of country-specific flexibility options.

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.

4.2.4.3 EU and National Forestry Strategies

The EU Forest Strategy for 2030 (71) sets a vision and actions to improve the quantity and quality of EU forests and strengthen their protection, restoration and resilience. It aims to adapt Europe's forests to the new conditions, weather extremes and high uncertainty brought about by climate change. 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. After reaching out to the forestry ministries of the seven aforementioned member states, the responses from Spain and Germany made clear that most countries have decentralized their forestry sectors.

<u>Spain</u>

The Ministry for the Ecological Transition and the Demographic Challenge of Spain explained that the country does not have any recent national forestry strategies, with their last approved plan dating back to 2002. They explained that "the responsibilities in forest planning and forest management are the responsibility of the autonomous communities, which have forestry plans in their area".

Germany

Although Germany does have a national forestry strategy 2050 (67) containing the country's vision for their forests for the period 2020-2050, their Federal Ministry of Food and Agriculture states that "forest management in Germany is very much decentralized. At the Federal level there is no central planning of afforestation areas or forest management activities. Forest policy strategies on federal level focus on forest development in general and framework conditions for forestry and timber industry such as state aid schemes and national programmes to stimulate sustainable forest management and efficient use of wood".

Austria

The Austrian forestry strategy, the "Österreichische Waldstrategie 2020+", even states that "the document was purposely kept more visionary than earlier forestry programmes" and that "individual parties are required to find their own ways to reach the common goals". Furthermore, the strategy is limited for the period until 2030 (68).

In summary, none of three countries mentioned above have concrete national plans and in all three the regional political bodies are in charge of the forestry targets.

The Netherlands

The Dutch national forestry strategy is probably the most concrete and specific, giving chosen measures per forestry target, such as the rejuvenation of forests to increase their vitality. Furthermore, the forestry strategy gives specific numbers: The Netherlands want to expand forests within the "Natuurnetwerk Nederland" (Nature Network Netherlands, hereafter NNN) by 15.000 ha and want to stimulate forest owners to expand the forest systems outside the NNN by 19.000 ha. They even specify how much area is available for afforestation in different nature types, such as along great rivers and in combination with agriculture. However, the Dutch forestry strategy has two important drawbacks: the strategy does not give an outlook for the period after 2030 and no specific time steps are given in which the country wants to implement all the measures (69).

Finland

Finland's forestry strategy only dates to 2025, giving a very limited outlook for their long term forestry strategy. Furthermore, the strategy was set up as visionary, giving general targets, but no specific methods (70).

For the remaining countries, namely France and Romania, no publicly available forestry plans were found and no response from their forestry ministries was received as of February 2022. Therefore, it was assumed in this study that these countries do not have any concrete climate or forestry roadmaps.

4.3 Conclusions

Based on the results found in this study, 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.

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5 Historic and current European supply of timber

5.1 Introduction

Apart from the assessment to what extent temporary carbon storage can contribute to mitigating climate change (see chapter 12), the question arises whether the current use or an increase in the use of forest materials can be accommodated in the first place. This chapter provides an assessment of the European data on mass supply of timber.

5.2 Methodology

5.3 Shares of countries with (in)sufficient resources

A large variation in self-sufficiency regarding national timber can be observed, but across member states forests grow faster than is harvested. To determine the availability of resources two balances where reviewed; production of under-bark wood versus consumption, and net annual increment of forests versus fellings. This was done for the current 27 member states of the European Union and Norway, with the latter covering a significant land mass within the European Economic Area.

Table 5.1 presents production, net trade, and apparent consumption of roundwood (incl. derived and associate wood resources). This data comes from the FAO's Joint Forest Sector Questionnaire of 2019, with all numbers expressed as sawn wood equivalent (SWE) under-bark cubic metres. Data is available for production, wood extracted from forests, and import and export of roundwood (reported as Sawn Wood Equivalent (SWE) excluding bark / under bark). From these data, the apparent consumption was determined as the summation of production and net trade (import-export). Hence any imbalance is reflected in net-trade of roundwood. It is important to emphasize that finished products such as sawn wood, veneer and plywood are not included in the trade statistics, so the imbalance covers rough wood and half products.

The balance of under-bark wood shows great variation amongst member states regarding the difference between production and apparent consumption, suggesting a divers picture across the European Union regarding self-sufficiency.

The imbalance between production and apparent consumption varies greatly amongst member states, which is presumed to be corrected by net trade. An interesting observation is that some of the largest producers in the EU are still a net importer of wood. While most medium and small producer are net exporters. Overall, the European Union was a net exporter in 2019, with 0.01% of overall production. Although this is the result of a trend in which the EU-27 went from net-importer to net-exporter since 2019.

Table 5.1

Overview of roundwood production, net trade, and apparent consumption (72)

Country	Production of roundwood [SWE m^3]	Net trade roundwood (import-export) [SWE m^3]	Apparent consumption [SWE m^3]
Austria	18.903.715	**10.052.236**	28.955.951
Belgium	5.212.140	**1.988.151**	7.200.291
Bulgaria	6.163.699	**-352.066**	5.811.633
Croatia	5.619.722	**-778.000**	4.841.722
Cyprus	9.366	**10.219**	19.585
Czech Republic	32.586.000	**-12.981.256**	19.604.744
Denmark	3.842.100	**-58.219**	3.783.881
Estonia	10.883.030	**-2.317.412**	8.565.618
Finland	63.666.864	**4.876.061**	68.542.925
France	49.630.974	**-2.923.755**	46.707.219
Germany	77.820.994	**-1.414.492**	76.406.502
Greece	1.359.105	**162.540**	1.521.645
Hungary	5.575.423	**-390.112**	5.185.311
Ireland	3.540.623	**274.059**	3.814.682
Italy	18.366.548	**3.705.751**	22.072.299
Latvia	12.942.170	**-2.528.057**	10.414.113
Lithuania	6.688.000	**-1.845.806**	4.842.194
Luxembourg	384.885	**176.443**	561.328
Malta	0	**1.571**	1.571
Netherlands	2.805.000	**-497.743**	2.307.257
(Norway)	(12.568.431)	**(-3.104.734)**	(9.463.697)
Poland	43.267.933	**-2.932.302**	40.335.631
Portugal	13.517.883	**1.594.653**	15.112.536
Romania	15.827.246	**1.015.614**	16.842.860
Slovakia	8.956.874	**-129.155**	8.827.719
Slovenia	4.618.159	**-1.317.939**	3.300.220
Spain	18.355.926	**-1.433.527**	16.922.399
Sweden	75.472.000	**7.987.232**	83.459.232
European Union (27)	*506.016.379*	***-55.311***	*505.961.068*

The balance of forest resources appears to have a surplus in the EU-27, suggesting that there is sufficient forest annual growth to meet current demand for round wood and the round wood processing industry within the EU. This however does not indicate that consumption within the building and construction sector – the focus of this study– is covered by round wood harvested within EU, but merely that demand from round wood processing industrial sectors within the EU is likely covered by harvests within the EU. This does not take into account import or export of wood products such as sawn wood, panel, plywood, products from outside the EU.

5.4 Annual forest growth

The net annual increment is the measure of the yearly increase in forest stand, the volumetric amount of wood above ground, after correction for natural losses. The balance between this and amount of wood annual harvested, fellings, indicates whether forests are growing or contracting in terms of overall standing volume. . If more wood is felled than the net annual increment, the forest will decrease due to human intervention. The balance and terms are shown in Figure 5.1.

<table>
<tr><td colspan="4">Gross increment</td></tr>
<tr><td rowspan="3">Natural losses</td><td colspan="3">Net increment</td></tr>
<tr><td colspan="2">Fellings</td><td rowspan="2">Net change</td></tr>
<tr><td>Logging residues</td><td>Removals</td></tr>
</table>

Figure 5.1
Overview of forest resources balance and corresponding definitions

In Figure 5.2 a selection of European countries are shown, taken from State of Europe’s forests (73) 2020, showing net annual increment and fellings per country for 2015 (stem wood over bark, million cubic meters). It shows that in all selected countries, the net annual increment was greater than felling, resulting in a greater forest stand by the end of 2015. Based on Annex 9 of the State of Europe’s forest 2020 report, no EU member state had more fellings than net annual increment based on the latest available data. This is reflected in the EU-28 average of 75% (net annual increment is felled).

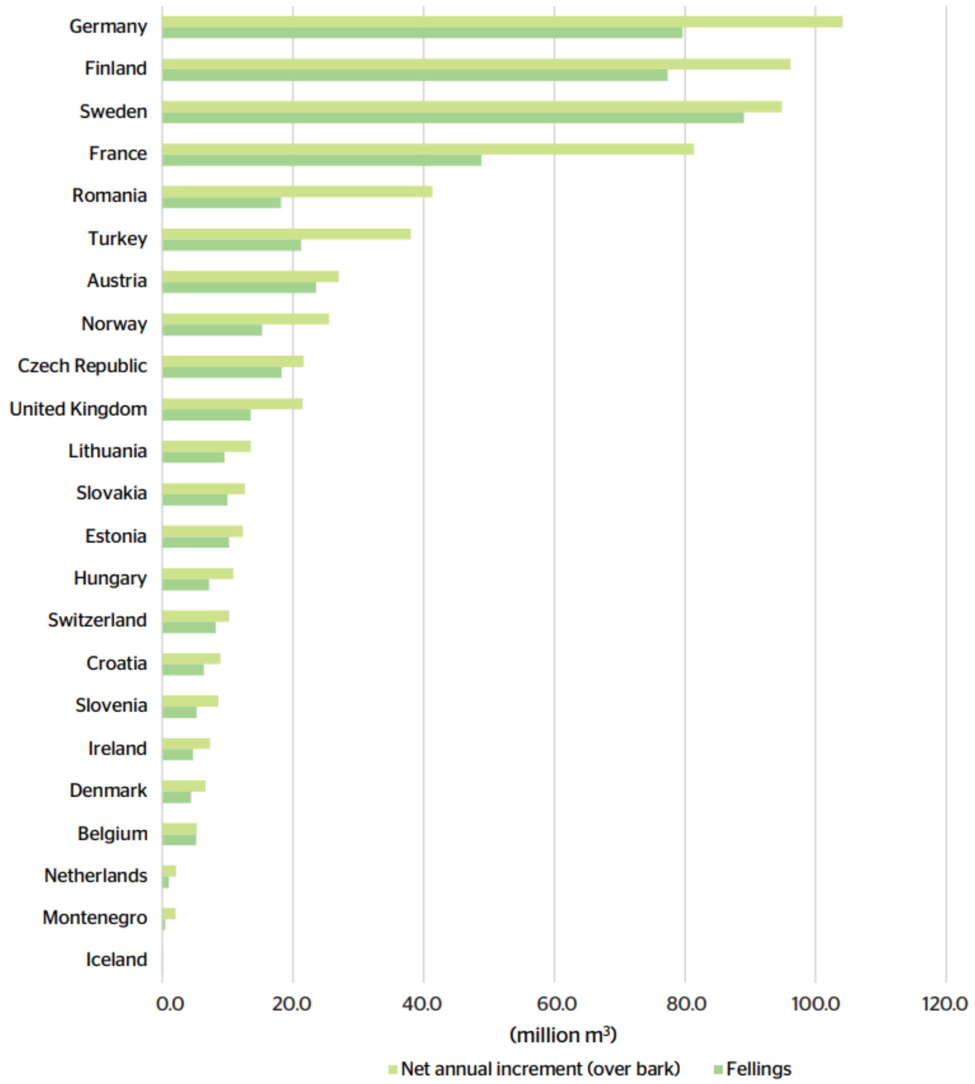

Figure 5.2
Annual fellings and net annual increment of selected countries, 2015, from State of Europe's forests (73). Elucidation: reported fellings are similar with 'round wood production' figures reported in Table 5.1. They differ because reported figures refer to different years and because figures report to either under bark (Table 5.1) or over bark (bark included, Figure 5.2). Bark makes up approximately 10% - 15% of stem weight and volume.

These findings suggest that in general there are sufficient resources in EU-27 member states to meet current needs for roundwood, but that perhaps due to economic, legal and environmental drivers certain member states are reliant on import of roundwood to meet demand. This highlights the diversity and ambiguity amongst the various member states regarding timber supply and self-sufficiency.

5.5 Breakdown of supplies from various forest types

Although centralized data on supplies per forest type are available, the data on forest type area shows a varied distribution across the European Union. This suggests that the source, regarding forest type, can vary greatly for each member state. This could be a reflection of a member state forestry history and geographic topography: for example, the many plantation forests in Northwest Europe due to extensive forest harvesting in the past, and island member state with limited land.

The following definition of forest types is followed here (74):

Planted forest:
Forest area where more than half of the trees have established through planting or deliberate seeding.

Naturally regenerated forest:
Forest area predominantly composed of trees that have established through natural regeneration. With naturally regenerated trees making up the majority of the forest. This can be a mixed native and non-native species. As well as include forests where no distinction can be made between planted and naturally regenerated trees.

Primary forest:
Forest area of naturally regenerated native species, with no clearly visible indication of human activities and the ecological processes are not significantly disturbed.

In Table 5.2, an overview is given for a selection of states (EU27 + Norway) of the total forest area in 2017, with corresponding shares of planted, naturally regenerating, and primary forests. For each state, the highest share of a specific forest type is highlighted in bold. Data was taken from the FAO database (72). FAO categorizes forest area either has planted forest or naturally regenerating, with the two categories added up to the total. Primary forests, natural forests undisturbed by humans, are reported separately. In the table the area primary forests has been deducted from the area of naturally regenerating forest to come to the overall percentage distribution per state.

Table 5.2

Overview of selected states' total forest area and shares of forest types (planted, naturally regenerating, and primary forest, of total forest area)

Country	Total forest area [ha]	% planted forest	% naturally regenerating (*excl. primary*)	% primary forest
Sweden	**27.980.000**	47.9%	43.5%	8.6%
Finland	22.409.000	32.9%	66.1%	1.0%
Spain	18.559.300	13.9%	86.1%	0.0%
France	17.002.800	13.7%	86.3%	0.0%
Norway	12.156.600	0.9%	**97.8%**	1.3%
Germany	11.419.000	50.0%	50.0%	0.0%
Poland	9.447.000	78.0%	21.1%	0.6%
Italy	9.404.700	6.8%	92.2%	1.0%
Romania	6.929.050	12.9%	83.0%	4.1%
Greece	3.901.800	3.6%	96.4%	0.0%
Austria	3.888.380	43.0%	54.0%	2.9%
Bulgaria	3.854.000	20.9%	63.6%	**15.5%**
Latvia	3.399.180	13.2%	86.3%	0.5%
Portugal	3.312.000	68.1%	31.2%	0.7%
Czech Republic	2.671.660	**95.3%**	4.3%	0.4%
Estonia	2.438.400	8.8%	88.8%	2.4%
Lithuania	2.196.000	27.5%	71.3%	1.2%
Hungary	2.057.270	38.3%	61.7%	0.0%
Croatia	1.931.608	3.8%	95.8%	0.4%
Slovakia	1.925.900	38.9%	59.9%	1.2%
Slovenia	1.243.930	3.7%	92.4%	3.9%
Ireland	770.020	86.0%	14.0%	0.0%
Belgium	689.300	63.6%	36.4%	0.0%
Denmark	625.600	70.9%	23.7%	5.4%
Netherlands	366.700	89.3%	10.7%	0.0%
Cyprus	172.590	18.9%	73.4%	7.7%
Luxembourg	88.700	33.8%	66.2%	0.0%
Malta	420	9.5%	90.5%	0.0%
European Union (27)	*158.684.308*	*66.9%*	*30.6%*	*2.6%*
EU27 + Norway	*170.840.908*	*62.2%*	*35.4%*	*2.5%*

The variation between EU member states becomes more apparent when plotting the share of planted forests against the productivity per hectare of total forest area, see Figure 5.3. It shows the relation between forest productivity and area share of planted forests. From this figure, it is apparent that member states with more than 50% of their forests being planted, have above EU average productivity. On the other hand, member states with less than 50% of their forests being planted, are within the bandwidth between 0 and 5 cubic meters per forest hectare productivity. The latter includes Sweden and Finland, two of the top 3 largest producers, but with below EU average productivity.

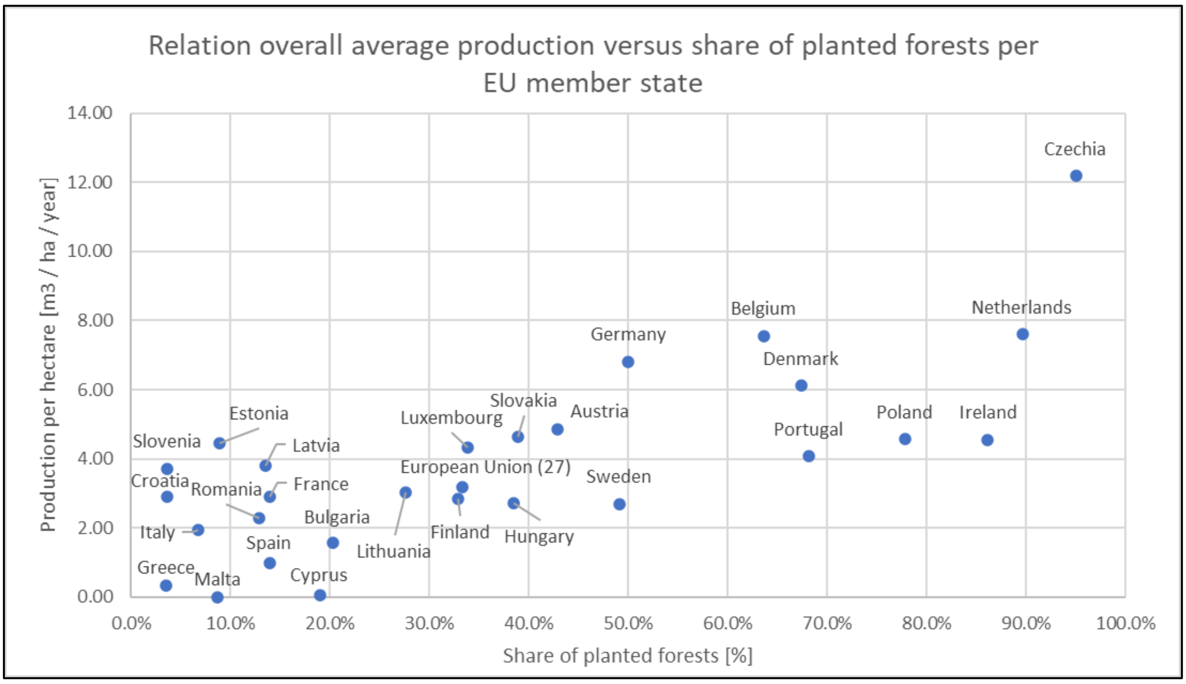

Figure 5.3
EU member states distribution regarding production per hectare and share planted forests. Production refers to fellings (over bark)

These findings seem to suggest that the type of forest has influence on productivity, but also that each member state has unique conditions that determine productivity (for example; climate, historic forestry activities and available area).

Figure 5.4 shows the share of forest covered by either FSC, PEFC, or both, and the total share of certified forest. The data from certified forest area is from FSC's and PEFC's own monthly reporting, and covers both forest and other wooded land. The red boxes highlight the five largest producers in the EU, representing more than half of EU production. These five countries have at least 60% or more of their forests certified.

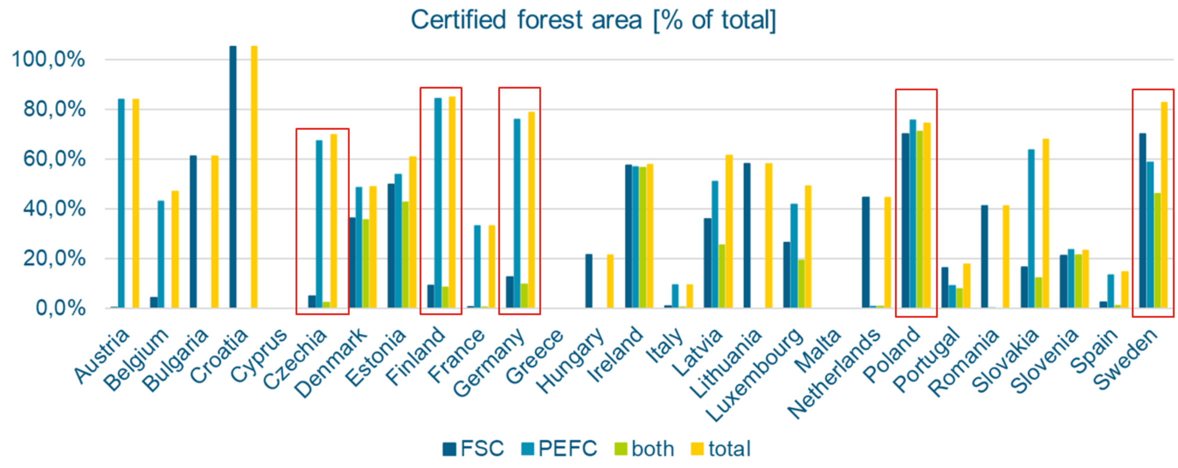

Figure 5.4
Share of forest under third party Forest management certification, FSC and PEFC.

Figure 5.4 shows that a large share of European forests seem to be covered by a sustainable forest management certification, suggesting a significant share of forests and wood harvested are certified. One member state stands out: together with the total forest area data of FAO from 2019, data for Croatia shows a mismatch resulting in 105% certified forest. This reflects differences in definitions and availability of recent data.
Overall these data indicate that further research at the national and local level would be needed to trace wood supplies from specific forest types, in order to draw conclusions on the effect of wood consumption on forest types.

5.6 Conversion of primary forest to plantations within the EU

Table 5.3 shows a historic overview of planted vs. primary forest area. This to deduce how over time the area of planted forests and primary forests have changed, and any possible indication of conversion of primary forests into plantation forests within the EU.

Table 5.3
Overview of planted and primary forest areas [x1000 hectares] per member states (EU27 + Norway) from 2000 to 2019, (73)(75).

Member state	Item	2000	2005	2010	2015	2016	2017	2018	2019
Austria	Planted Forest	1684	1682	1679	1675	1674	1673	1673	1672
	Primary Forest	114	114	114	114	114	114		
Belgium	Planted Forest	408	407	406	438	438	438	438	438
	Primary Forest	0	0	0	0	0	0		
Bulgaria	Planted Forest	933	875	817	824	817	807	797	787
	Primary Forest	270	304	597	597	597	597		
Croatia	Planted Forest	82	78	75	75	75	73	72	70
	Primary Forest	7	7	7	7	7	7		

Member state	Item	2000	2005	2010	2015	2016	2017	2018	2019
Cyprus	Planted Forest	28	29	31	31	32	33	33	33
	Primary Forest	13	13	13	13	13	13		
Czech Republic	Planted Forest	2590	2580	2570	2553	2550	2547	2545	2542
	Primary Forest	9	9	10	10	10	10		
Denmark	Planted Forest	447	447	447	460	454	444	433	423
	Primary Forest	32	31	32	34	34	34		
Estonia	Planted Forest	198	202	207	214	214	216	216	216
	Primary Forest	48	52	55	58	58	58		
Finland	Planted Forest	5145	6027	6908	7368	7368	7368	7368	7368
	Primary Forest	230	230	230	230	230	230		
France	Planted Forest	1586	1830	2073	2260	2295	2330	2364	2399
	Primary Forest	0	0	0	0	0	0		
Germany	Planted Forest	5677	5691	5705	5710	5710	5710	5710	5710
	Primary Forest	0	0	0	0	0	0		
Greece	Planted Forest	129	134	139	139	139	139	139	139
	Primary Forest	0	0	0	0	0	0		
Hungary	Planted Forest	794	794	794	793	790	787	791	790
	Primary Forest	0	0	0	0	0	0		
Ireland	Planted Forest	549	594	640	658	660	662	666	670
	Primary Forest	0	0	0	0	0	0		
Italy	Planted Forest	596	615	634	640	641	642	643	644
	Primary Forest	93	93	93	93	93	93		
Latvia	Planted Forest	322	365	408	437	442	448	454	460
	Primary Forest	17	16	15	16	16	16		
Lithuania	Planted Forest	466	501	536	585	596	604	605	608
	Primary Forest	21	26	26	26	26	26		
Luxembourg	Planted Forest	28	29	30	30	30	30	30	30
	Primary Forest	0	0	0	0	0	0		
Malta	Planted Forest	0	0	0	0	0	0	0	0
	Primary Forest	0	0	0	0	0	0		
Netherlands	Planted Forest	314	323	333	325	326	328	329	330
	Primary Forest	0	0	0	0	0	0		
Norway	Planted Forest	115	115	115	108	108	108	108	108
	Primary Forest	160	160	160	160	160	160		
Poland	Planted Forest	7366	7366	7366	7366	7366	7366	7366	7366
	Primary Forest	51	54	56	59	59	59		
Portugal	Planted Forest	2268	2245	2222	2256	2256	2256	2256	2256
	Primary Forest	24	24	24	24	24	24		
Romania	Planted Forest	528	534	540	957	895	895	895	895
	Primary Forest	263	264	269	283	283	283		
Slovakia	Planted Forest	755	748	741	747	747	749	749	749
	Primary Forest	24	24	24	24	24	24		
Slovenia	Planted Forest	48	58	67	45	45	46	46	45
	Primary Forest	53	49	49	49	49	49		

Member state	Item	2000	2005	2010	2015	2016	2017	2018	2019
Spain	Planted Forest	2391	2494	2597	2620	2584	2587	2588	2589
	Primary Forest	0	0	0	0	0	0		
Sweden	Planted Forest	10318	11400	12481	13226	13213	13392	13565	13739
	Primary Forest	2417	2417	2417	2417	2417	2417		
EU-27	*Planted Forest*	*45647*	*48046*	*50444*	*52429*	*52357*	*52569*	*52769*	*52967*
	Primary Forest	*3687*	*3728*	*4032*	*4055*	*4055*	*4055*		

Overall primary forests increased in the European Union (27) between 2000 and 2017, from 3.612.048 to 4.054.548 hectares. This shows that total decreases in primary forest area rarely occur in the European Union, suggesting that conversion to plantation is a limited risk. Two member states have reported a year-on-year decrease of primary forest area between 2000 and 2017 (Latvia and Slovenia). These two members state also had years where planted forest area increased at the same time. As no direct data on land conversions was to hand, it cannot be concluded whether this was a case of land use conversion or a decrease on one plot of land and an increase elsewhere. In both cases the planted forests increased more than the decrease in primary forest, suggesting at least further land use conversion from other land use types.

5.7 General findings

These findings 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 discussed in the previous sections.

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 an uniform definition and differing results between various sources of data. This is raised and reported in several publications (72)(76).

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 sound 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 utilized, an increase in demand may not constitute an *a priori* shortage.

Further scoping to research timber supply on a local level of specific member states and with emphasis on specific species and products is provided in the next chapter.

5.8 References

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6 Wood balances of selected EU member states

6.1 Introduction

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. Thus giving insight into how these factors influence the wood supply chain in these member states, and thus explain the difference between member states and their relations.

6.2 Methods

To gain greater detail on member states, desk research was performed per member state by looking for institutional or academic sources at a national level. Not only to gain better data regarding the flows of materials of certain types or on a finer geographic scale, but also to gain the local context of the data through the reports.

Following the collection of various sources per member states, the information was interpreted and compared to reconstruct the wood balance per member state, with a preference for the most recent and complete set of data. For the wood balances, data for the same year and source was used as much as possible to maintain consistency, especially because measurement or data collection methodology and definitions can differ significantly between sources. The wood balance covers the stages from harvested wood for forests, primary wood from sawmills, secondary wood products after further processing (e.g. planing wood), to wood used in construction. This final stage focuses in particular on Cross Laminated Timber (CLT) and Glued Laminated Timber (GLT), as these require additional process step(s) after planing of wood.

The following definitions apply:
Sawn wood: Sawnwood is wood that has been produced either by sawing lengthways or by a profile-chipping process

SWE: Sawn wood equivalent

Sawlogs/sawwood: Is a felled tree trunk suitable for cutting up into timber

Roundwood: Same as sawlogs/sawwood

The key findings are presented alongside the wood balance per member state, following the stages of wood processing. These findings focus on the sourcing, production and trade at each stage, thus following wood from its origin to the share that is used in construction.

Despite best efforts to complete the wood balance for each member states, and account for each flow of material in the balance, gaps in data and explanation remain. This occurred with each member state, to a certain level. And similarly available data limited synchronizing the results of the wood balance per member state to allow comparisons between member states. Hence, no comprehensive and definitive conclusions can be drawn from the results. This would require extensive further research involving local partners of the specific member states.

6.3 Austria

Figure 6.1 shows an approximate balance for round timber and sawn timber in Austria (77). Despite sizeable fellings from its forests, Austria is dependent on the import of roundwood to meet the demand of its wood processing industry.

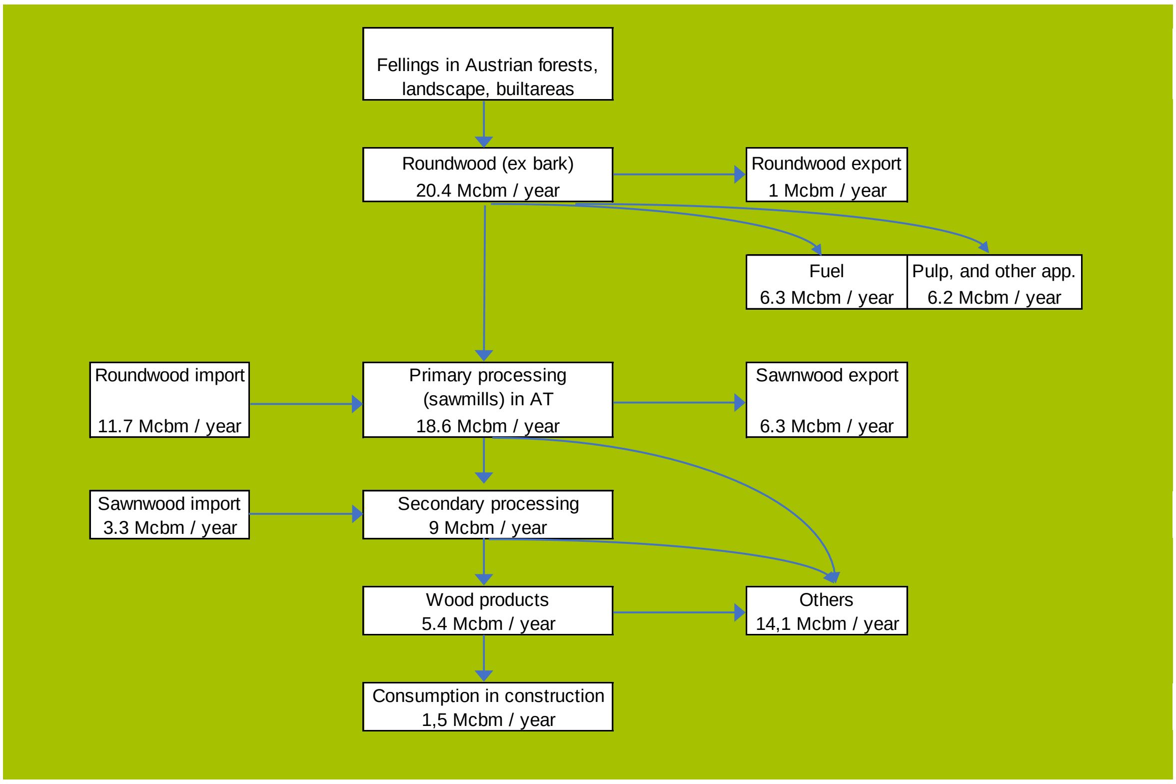


Figure 6.1
General wood balance focused on wood products of Austria, all data for 2019.

6.3.1 Roundwood

Annually, approximately 20 million m^3 (Sawn Wood Equivalent (SWE), under bark) of roundwood and woody material is harvested from forests products (77). Of which the majority came from small forest holders (<200ha) with 55% in 2020, followed by large forest holders (>= 200ha) with 34% and the remainder coming from the Austrian government-owned forests (78). The harvested wood originates for approximately 88% from forested land in Austria, with the remaining forests not being used for fellings (79)(100). The harvested roundwood consists of approximately 83% coniferous wood and 17% non-coniferous wood in 2020 (78).

About a third of the roundwood harvested from Austrian forests, approx. 7 million m^3 (SWE, under bark) in 2019, is consumed by Austrian sawmills (77). The rest is either consumed as fuel or pulp, or exported (approx. 1 million m^3, SWE, under bark, in 2019).

The majority of roundwood consumed by Austrian sawmills is imported roundwood, approx. 12 million m^3 (SWE, under bark) in 2019, to supplement national supply of roundwood for the relatively larger sawmill industry.
About 65% of the roundwood consumed by Austrian sawmills is converted into sawn product, and the remainder into by-products (chips, sawdust, shavings). Approximately half of the produced sawnwood is exported, while the rest is further processed in Austria to wood products (77).

Import of tropical roundwood is negligible, making up less than one percent of total roundwood imports (80).

6.3.2 Sawn timber

The majority of sawnwood used in Austria comes from Austrian sawmills, with the remaining one third being imported (77). Most of the imported sawnwood is coniferous wood, with about 10% being non-coniferous (81). While Austria also exports a large share of its sawnwood to neighbouring countries.

By far most of the of sawnwood imported into Austria originates from neighbouring countries, with a negligible amount sourced outside Europe (82). As shown in Figure 6.2, Germany and Czech Republic are the two neighbouring countries where about 65% of Austrian imported sawnwood is sourced from. The imported volume from Czech Republic, and to a lesser extent Finland, shows structural growth in the past five years. This has compensated fluctuations from other countries, resulting in stable imports of sawnwood into Austria in the past five years.

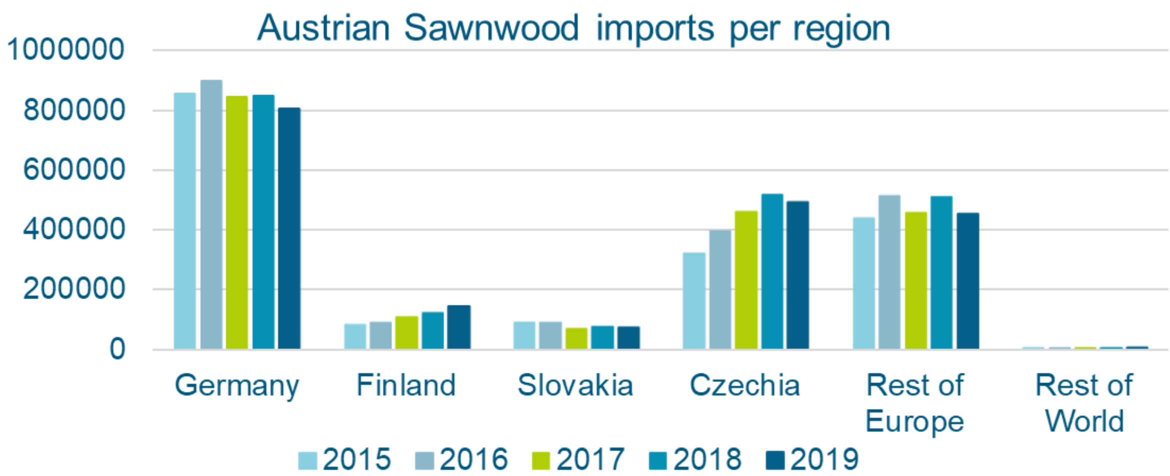


Figure 6.2
Overview of Austrian imported sawnwood volumes per trading country/region, over past five years.

From Austrian sawmills, about half of the produced sawnwood is exported, resulting in the export of sawnwood being about a factor 2 greater than the import. Most of the sawnwood is exported to neighbouring countries, as shown in Figure 6.3 (82). About 45% is exported to Italy, with the rest of Europe making up another 43%. Outside of Europe, Asia forms the primary export destination, with a large role for Japan. Overall in the past five years, export of Austrian sawnwood has grown, with about 4% per year on average.

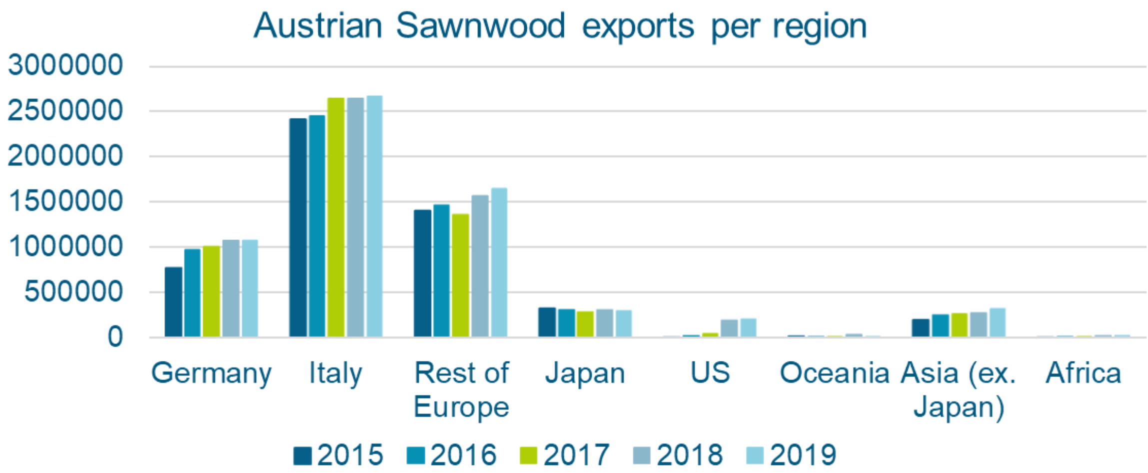
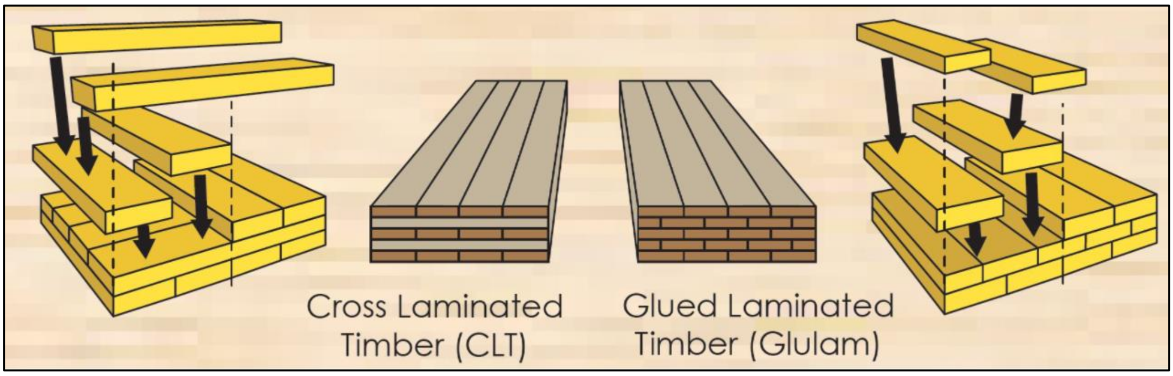


Figure 6.3
Overview of Austrian exported sawnwood volumes per trading country/region, over past five years

Sawnwood not necessarily means wood for construction and for other large products. Although Austria is known as a pioneer in laminated timber for construction. The laminated timber sector contributes about a quarter of the overall economic revenue for wood used in the buildings sector, with the rest being predominantly door and window frames and wooden flooring (83). What the share is of laminated timber, in terms of roundwood equivalent volume, of the overall shaved wood production is not clear.

Laminated timber

Besides roundwood and sawn wood there is a relatively new type of timber that is used in the construction industry: laminated timber. These are slats of timber that are glued together to make timber beams that are strong enough to compete with steel and concrete. The timber slats can be glued with the fibers is parallel orientation or perpendicular orientation, resulting in respectively glued laminated wood (GLT or glulam) and cross-laminated timber (CLT).



Most of the timber used for Glulam or CLT is conifer wood, mainly spruce because it can be glued well and is relatively cheap. It is possible to use a tropical hardwood for laminated timber, but this is harder to glue well and is more expensive.

Austria is the country with the largest production capacity for producing GLT with over 1,9 million m^3 per year. This is 51% of the total production capacity in Europe. Austria also has the largest capacity for CLT with circa 415.000 m3 per year. This is 43% of the European production capacity. More than half of Austrian produced laminated wood is exported to neighbouring countries, in terms of economic value (83), with Italy and Germany representing half of the export market. The use of wood as construction material has been rising in Austria in the last twenty year by 70%, resulting in 24% of buildings measured in usable floor area being made from wood in 2018 (84).

In the figures below the production capacity of the major production companies in Europe for GLT and CLT are shown. Annex I shows the tables with the production capacity and the country where the laminated timber is produced. It is estimated that approximately 80% of the production capacity for GLT and CLT is currently in use, resulting in an annual production of approximately 1,5 million m^3 per year. The 20% remaining is capacity that might be used in the future when demand for GLT and CLT is increasing.

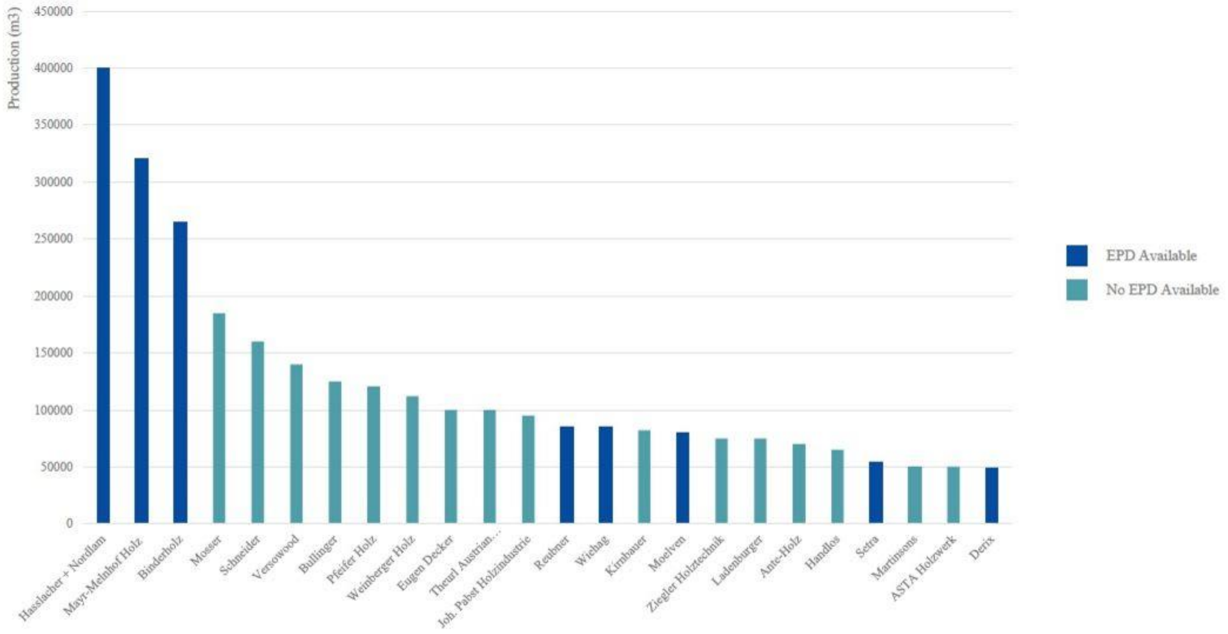


Figure 6.4
Capacity of production facilities for glulam in Europe

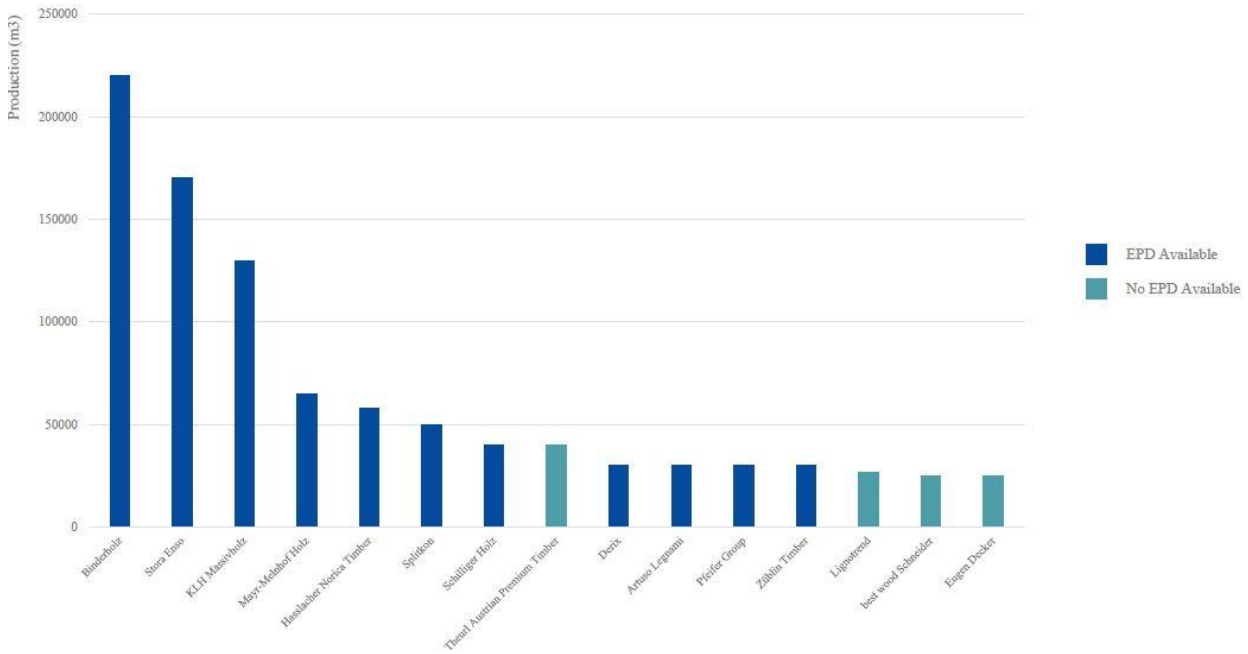


Figure 6.5
Capacity of production facilities for CLT in Europe

6.4 France

France’s forests cover 16,8 million ha and are growing to meet demand for timber products. France holds the fourth place among the most forested countries in the European Union. In the south of France afforestation rate is largest (see Figure 6.6). The species most represented in France are oak, beech, fir, spruce and Scots pine (85).

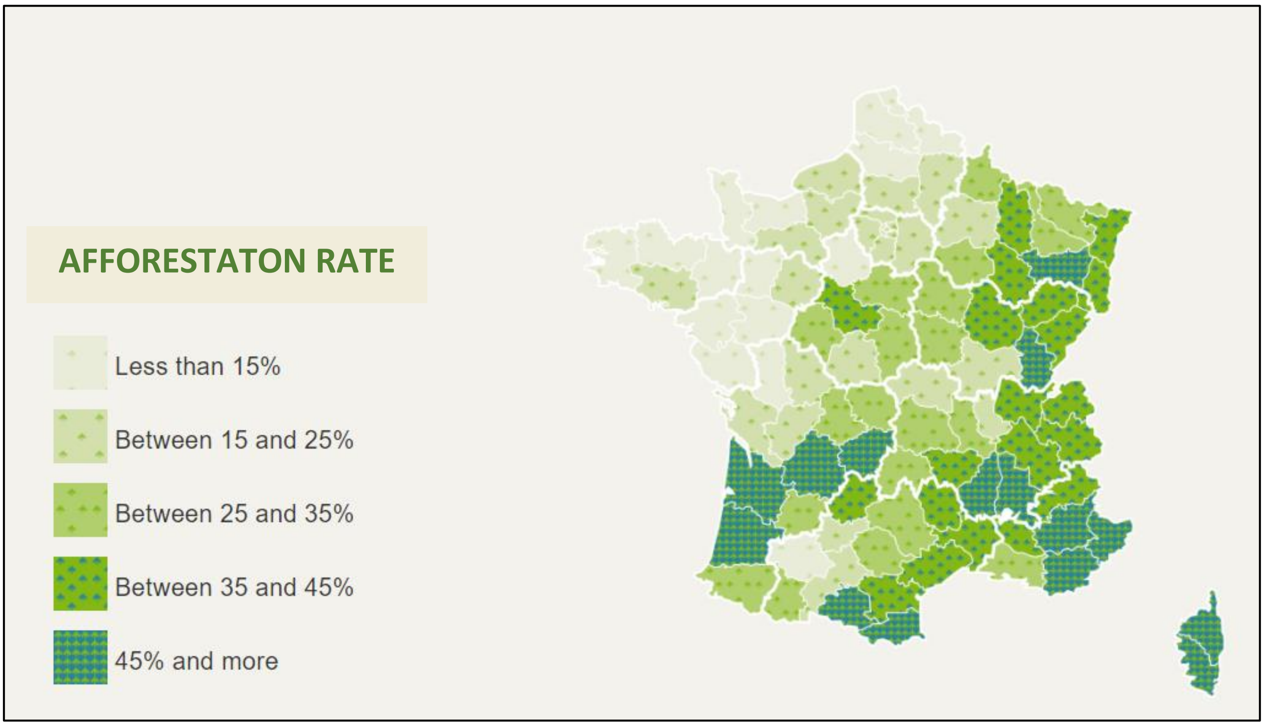


Figure 6.6
Afforestation rate of France (86)

In France over 33% of the forest has a PEFC certificate (1), this is circa 5,5 million ha and about 60% of the production timber in the country. 75% of the forests in France are privately owned and the other quarter is government property. The National Forestry Office is a public forest manager responsible for implementing the management plan and carrying out work on the forest of the state and the majority of public authorities (86). Therefore, all governmental forests should be sustainably managed and exploited.

France is one of the main importing countries for primary tropical product (Belgium and the Netherlands also being main importing countries) and largest importer of secondary tropical timber products (such as doors, mouldings, windows or other joinery). In the figure below the share of certified timber that is exported is shown. France is the second largest exporter of certified timber with over 100.000 m^3 RWE (round wood equivalents) export of which 67% is certified. This is a relative low share of certified timber compared with the other countries. The large contribution by the Netherlands stems from the relatively large volumes that pass through the main seaports (Rotterdam and Amsterdam harbours) on to other destinations.

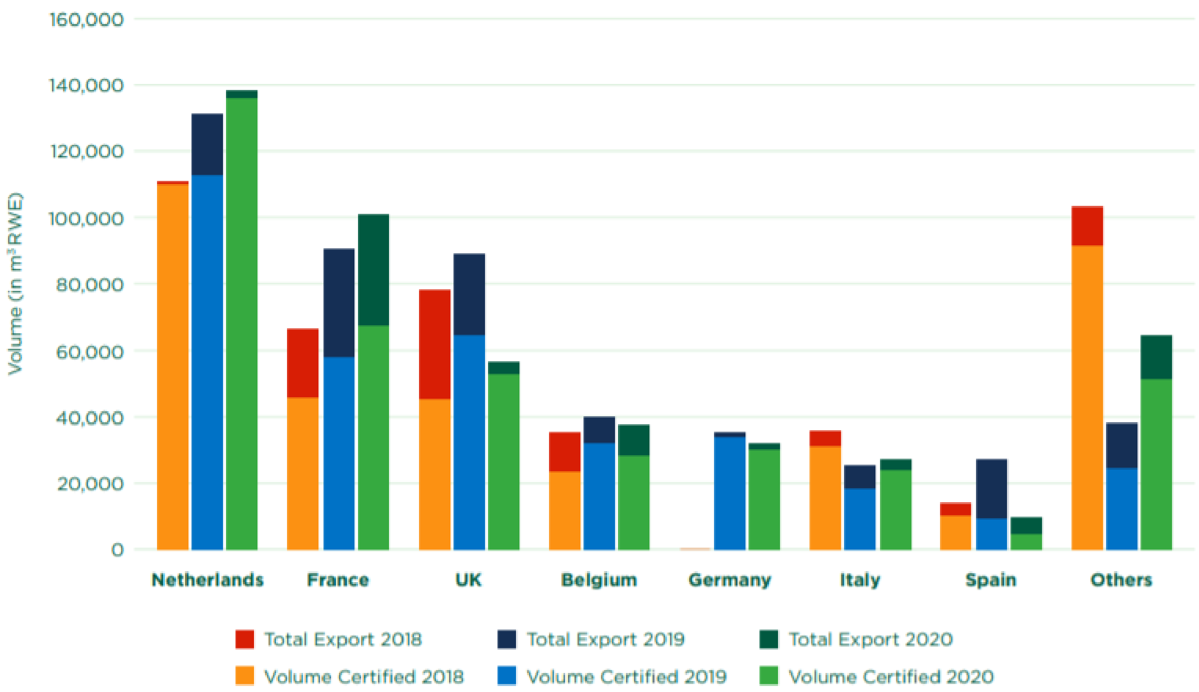


Figure 6.7
Total export volume to European countries by four reporting members and the volume sold with an FSC- or PEFC-certification in 2018, 2019 and 2020. Note that Germany was not specified as country of destination in the 2018 and was then included in the category 'Others' (87)

Figure 6.8 shows an approximate balance for round timber and sawn timber in France. With exception for data on secondary wood production, for which no data was found.

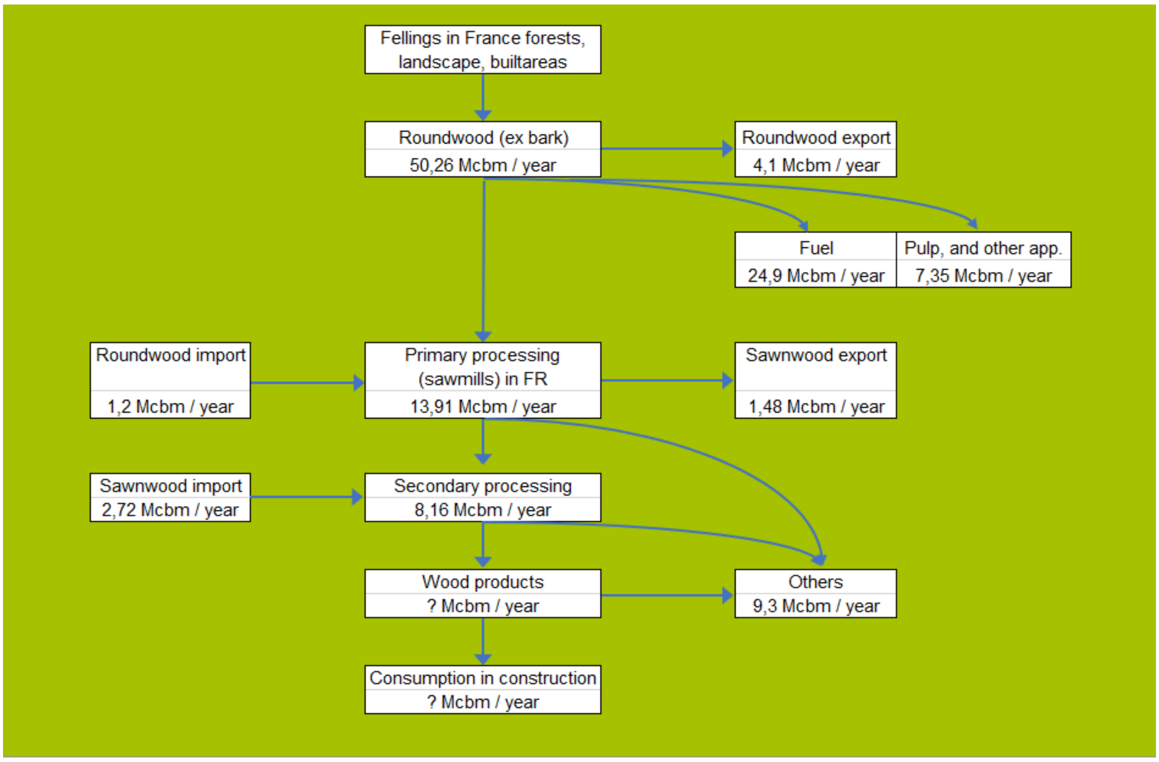


Figure 6.8
Wood balance for France, 2017

6.4.1 Roundwood

Around 16.7 million m^3 SWE (sawn wood equivalent) conifer roundwood is harvested in France and 8.6 million m^3 SWE non-conifer is harvested (2017). Both are specifically harvested for the industrial roundwood purposes. For fuel purposes almost 25 million m^3 SWE is harvested, 90% being non-conifer.

The sawmill industry processes 13.9 million m^3 SWE, this is 45% of the total material use of wood. The other industries that process wood are the panel industry 30% and the wood pulp industry 25%.

France exports more industrial roundwood that imports (2019). The *net* export of industrial roundwood is 942 thousand m^3 SWE conifer and 1.928 thousand m3 SWE non-conifer in 2017. In 2019 the *net* export of industrial roundwood is 693 thousand m^3 SWE conifer and 1.921 thousand m^3 SWE non-conifer. This means a slight decrease of export in two years time. Most of the roundwood export is to neighbouring countries such as Germany (28%), Belgium (26%) and Italy

(18%). Outside the EU, China is the largest importer of roundwood from France with 12% of total export volume.

The majority of the imported conifer roundwood is from Finland. Switzerland, Germany, Spain and Poland are also relatively large suppling countries of roundwood to France. Tropical roundwood is mostly sourced from Equatorial Guinea, Congo and the Central African Republic.

6.4.2 Sawn timber

In France, the production of conifer sawnwood in 2019 was 6.559 thousand m^3 SWE and 1.254 thousand m^3 non-conifer sawnwood.

Import of conifer sawn timber was mostly from Germany (23%), Finland (18%) and Russia (11%). Tropical sawn timber was mostly sourced from Cameroon (18%), Brazil (11%) and Belgium (9%). Export of sawn timber is mostly to neighbouring countries such as Germany, Belgium, Spain and Italy.

6.5 Finland

Finland is primarily an exporting country of processed forest industry products. In 2019, 90% of the forests in Finland are PEFC-certified. Figure 6.9 shows an approximate balance for round timber and sawn timber in Finland (80)(94)(98), with exception for data on wood consumption in construction, for which no data was found.

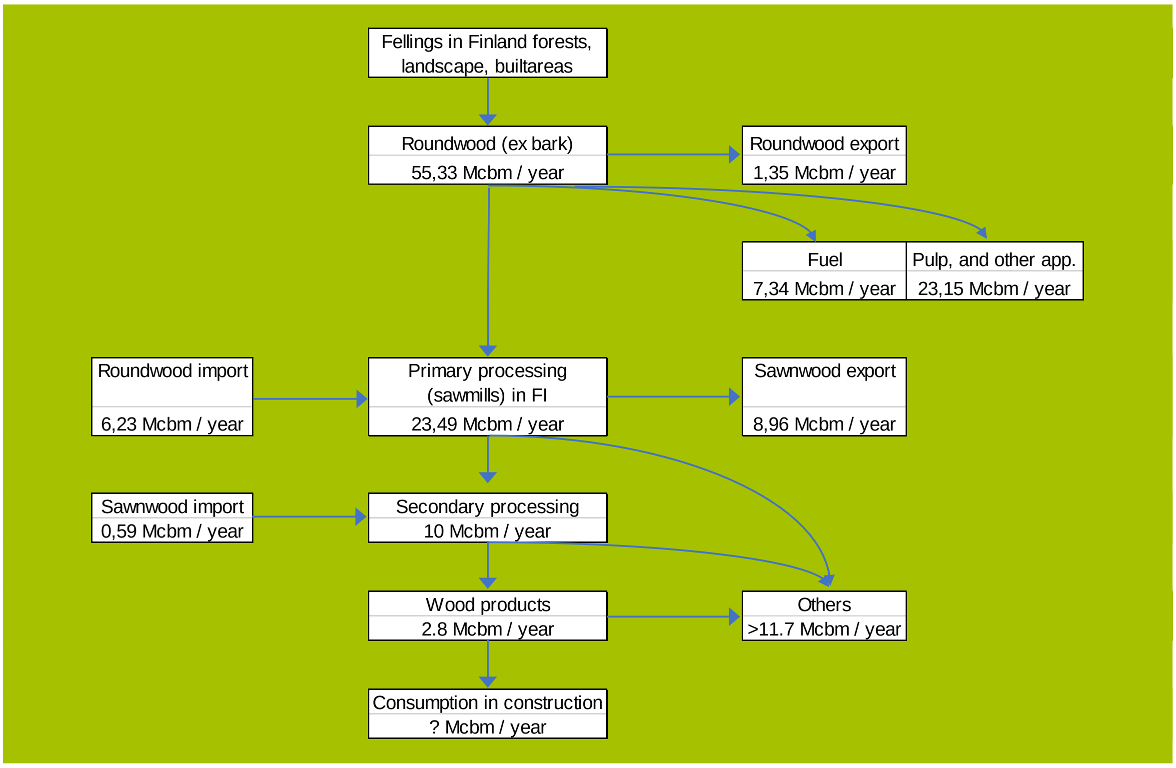


Figure 6.9
Wood balance for Finland, 2019

6.5.1 Roundwood

Around 46.5 million m^3 SWE conifer roundwood is harvested in Finland and 8.8 million m^3 SWE non-conifer is harvested. Both are specifically harvested for the industrial roundwood purposes. For fuel purposes 7.3 millionm^3 SWE is harvested, this is 12% of the total harvesting in Finland. Most of the harvested roundwood is cut for industrial purposes.

The sawmill industry processes 23.5 million m^3 SWE, this is 33% of the total material use of wood. The other industries that process wood are the panel industry 5% and the wood pulp industry 62%.

Finland imports more industrial roundwood than it exports, although sawnwood export is higher than import (2019). The net import of industrial roundwood is 570 thousand m^3 SWE conifer and 4308 thousand m^3 SWE non-conifer. Most import of roundwood is from Russia with almost 68% for conifer and 90% non-conifer. Export of roundwood is mostly to Sweden. However, import and export volumes are small compared to the volumes processed in the sawmill industry indicating that most roundwood is processed before exporting to other countries.

6.5.2 Sawn timber

In Finland the production of conifer sawnwood in 2019 was 11.4 million m^3 SWE and 30 thousand m^3 non-conifer sawnwood. The share of non-conifer sawnwood is negligible in Finland compared to conifer timber.

Finland has a relatively small amount of import of conifer sawn timber. Mostly is sourced from Russia (approximately 290 thousand m^3). Export of sawn timber is mostly to Egypt (11%), China (10%) and the UK (9%). As said before, the export of sawn timber (or otherwise processed timber) is higher than import, while industrial roundwood has a trade deficit. This indicates a well-developed timber process industry.

Finland has a yearly production capacity of GLT of 135.000 m^3, being 5% of the total production capacity in Europe. The country has a larger share in the production capacity for CLT with 170.000 m^3 per year. This is 18% of the total production capacity of CLT in Europe.

6.6 Germany

Figure 6.10 shows an approximate balance for round timber and sawn timber in Germany (88).

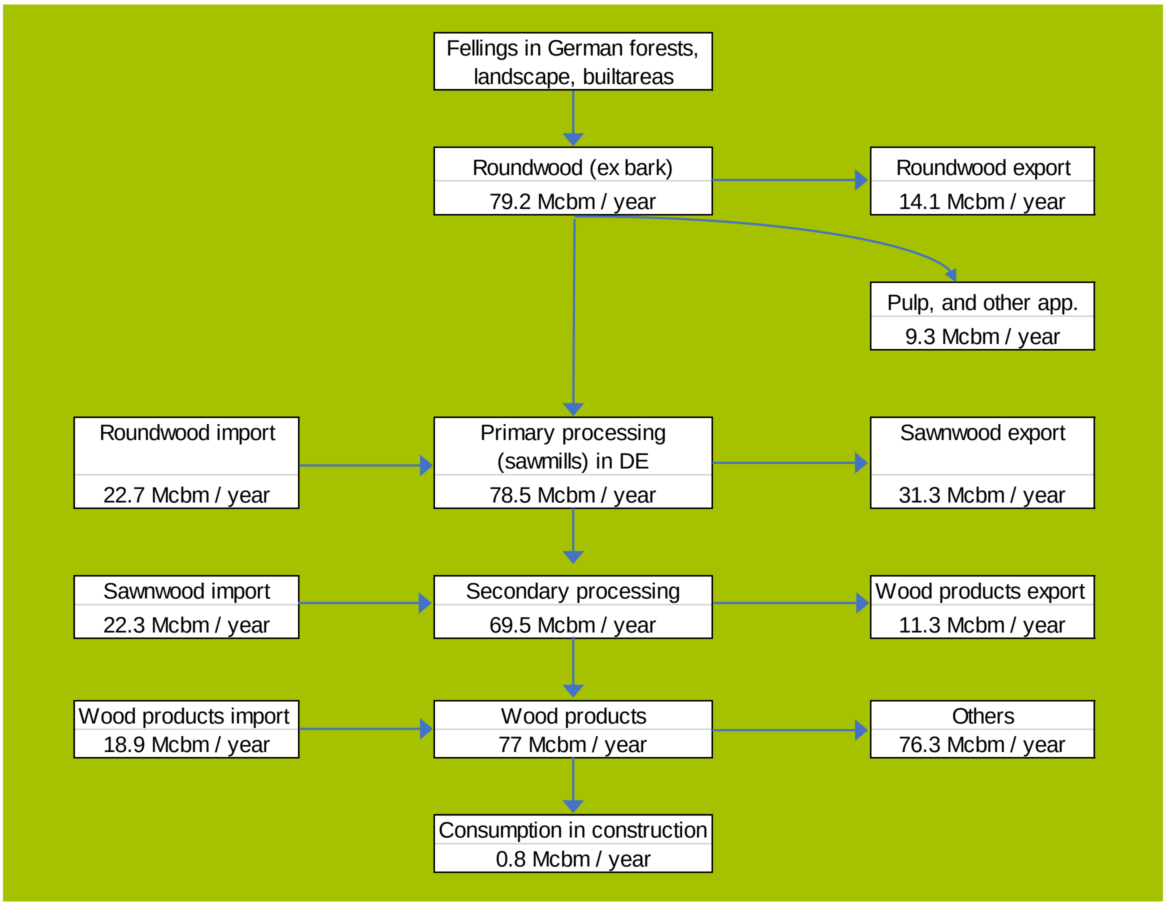


Figure 6.10
Wood balance for Germany, 2019

6.6.1 Roundwood

Annually, approximately 79 million m^3 (under bark) of roundwood and woody material is harvested from forests. Most wood is sourced from private forests (46%), followed by state forests (33%) and corporate forests (20%) (88). Approximately 75% of harvested roundwood in Germany are cuts due to damaged trees, in 2020, of which about two-thirds is due to damage by insects (89). This problem mainly affects spruce firs, which are the most common species in Germany. The harvested roundwood consists of approximately 73% coniferous wood and 27% non-coniferous wood in 2017 (90)

About 70% of the roundwood harvested from German forests, approx. 56 million m^3 (under bark) in 2019, is consumed by German sawmills. The rest is either consumed as pulp or fuel, or exported (approx. 14 million m^3, under bark, in 2019) (88).

The majority of roundwood consumed by German sawmills is nationally sourced roundwood. While approximately 22 million m^3 (under bark), in 2019, is imported to supplement national supply of roundwood for the relatively larger sawmill industry.
A high percentage of roundwood consumed by German sawmills appears to be converted into sawnwood, with the remainder becoming by-products (chips, sawdust, shavings). About 40% of the produced sawnwood is exported, while the other 60% is further processed in Germany to wood products.

Import of tropical roundwood is negligible, making up less than one percent of total roundwood imports (80).

6.6.2 Sawn timber

The majority of sawnwood used in Germany originates from German sawmills, with the remaining 30% is imported. Most of the imported sawnwood is coniferous wood, with less than 10% being non-coniferous. Germany also exports a quarter of its sawnwood to neighbouring countries (88).

By far, most of the of sawnwood imported into Germany comes from major European producers, with a negligible amount sourced outside Europe. As shown in Figure 6.11, Austria, Russian Federation, Belarus and Sweden are responsible for over half of sawnwood imported into Germany (91).

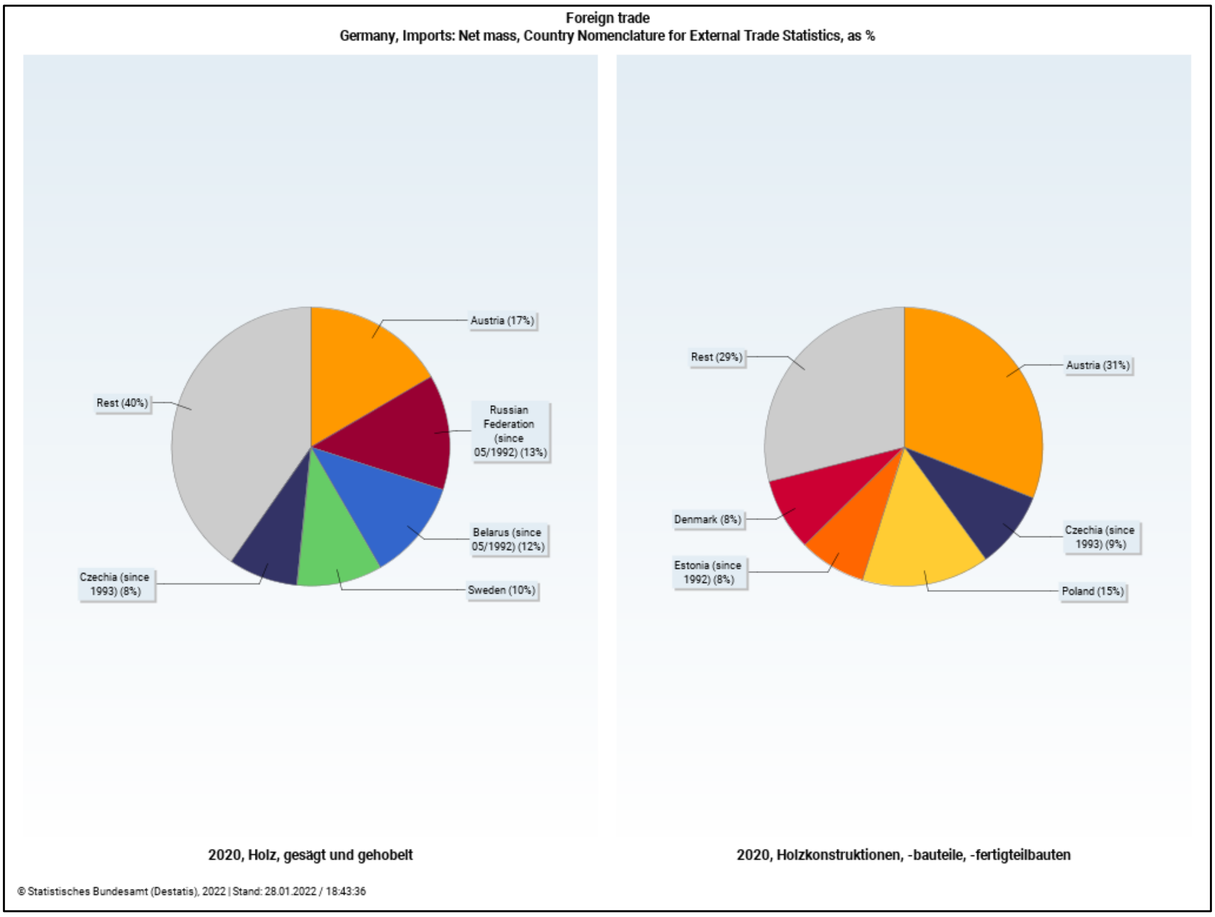


Figure 6.11
Overview of German imported planed sawnwood (left) and construction products (right) by mass with main trading country, in 2020

From German sawmills about a third of the produced sawnwood is exported, resulting in the export of sawnwood being about one and half times greater than the import. Most of the sawnwood is exported to neighbouring countries, as shown in Figure 6.12 (92). This is with exception of the United States of America, with 12% of the export mass share in 2020. Neighbouring European countries (Austria, Belgium, The Netherlands, and France) together constitute 40% of the export market by mass.

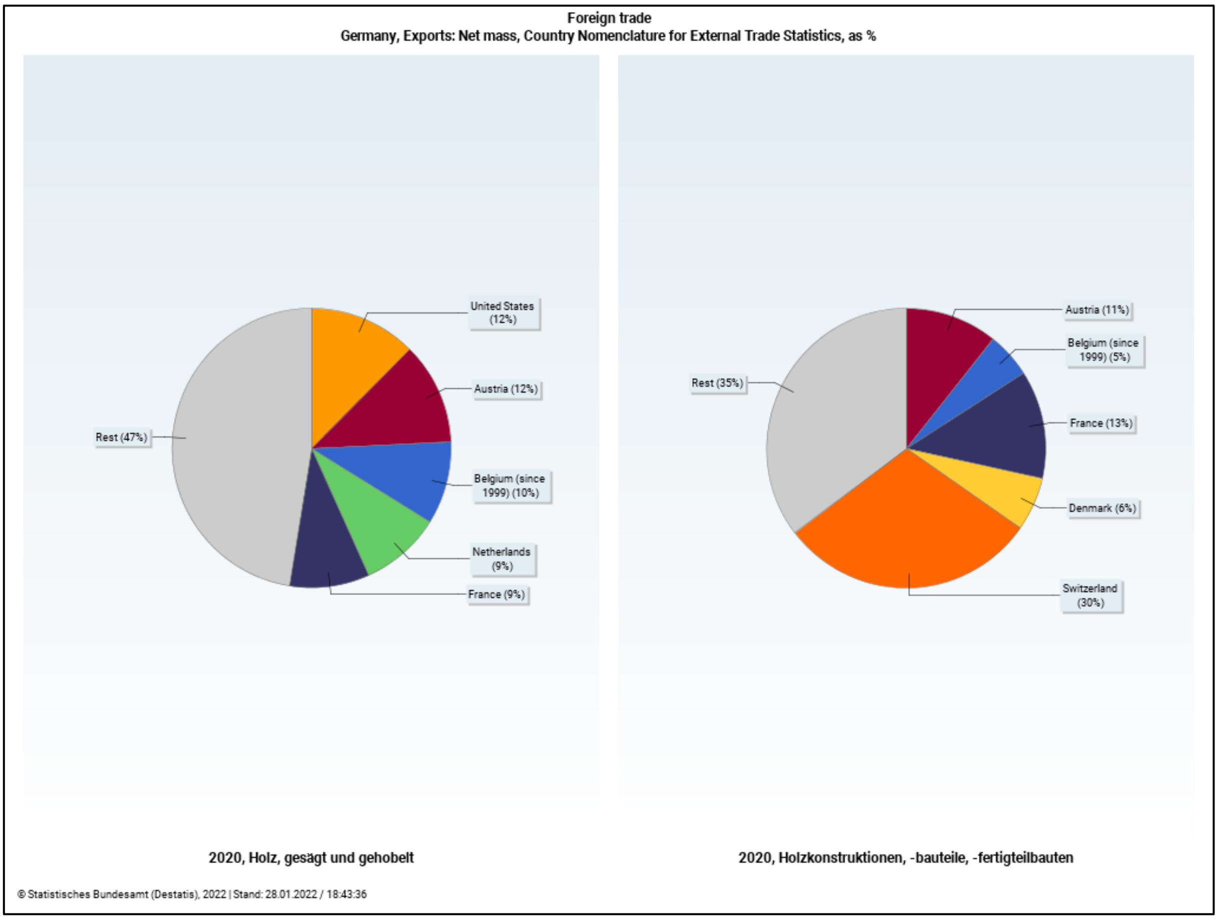


Figure 6.12
Overview of German exported planed sawnwood (left) and construction products (right) by mass with main trading country, in 2020

Sawnwood not necessarily means wood for construction and for other large products. The production of wooden construction elements (GLT and CLT) in Germany, with 700,000 to 900,000 m^3 of construction products per year (93), makes up approximately 1% of the overall wood production in Germany. Together with other construction elements, such as stairs and wall elements, the majority is traded with neighbouring European countries as shown on the right of Figure 6.11 for import and Figure 6.12 for export. Germany has the second largest production capacity for both GLT and CLT, respectively being over 1 million m^3 (36%) and 290 thousand m^3 (30%) of total production capacity. This means about two-thirds of GLT and CLT production capacity is used.

6.7 The Netherlands

Figure 6.13 shows an approximate balance for round timber and sawn timber in the Netherlands (94).

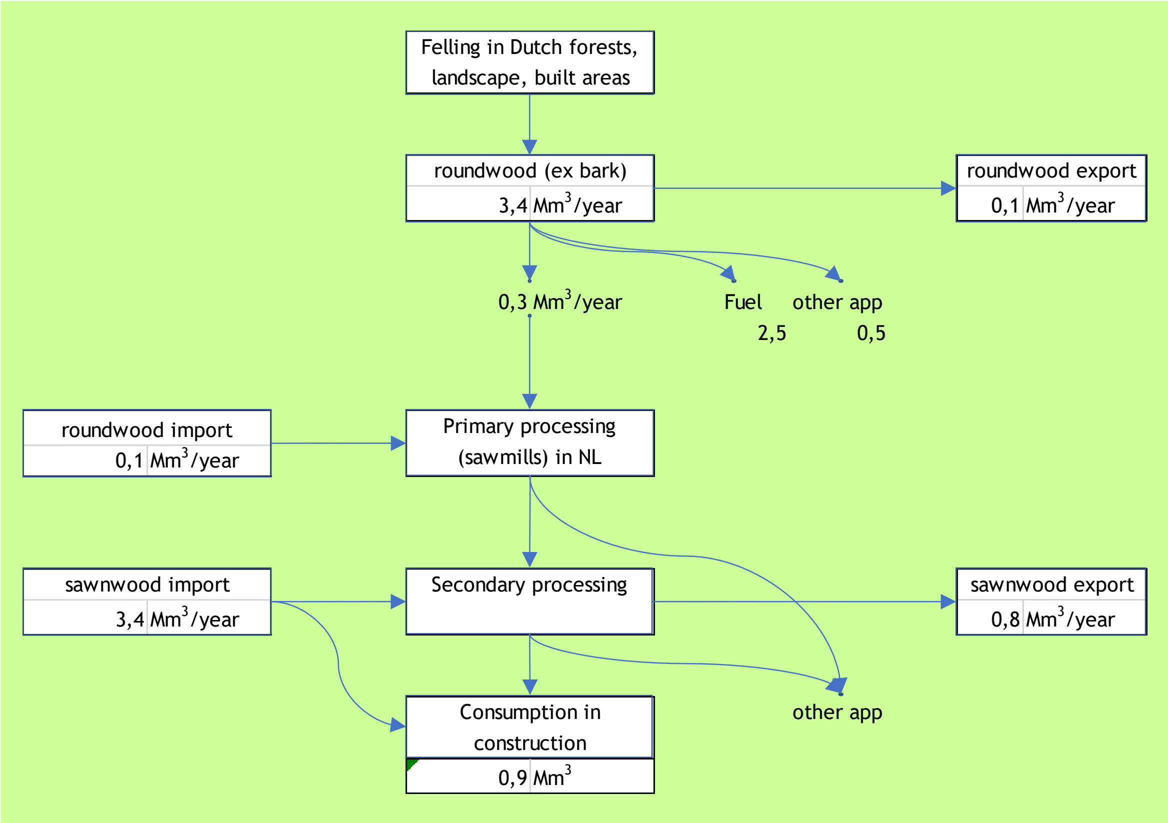


Figure 6.13
Global balance for roundwood in The Netherlands, 2018

6.7.1 Roundwood

Annually, approximately 3.4 million m^3 (under bark) of roundwood and woody material is harvested in forests (25%), landscape and built-up areas in the Netherlands.
About 20% of this – i.e. 700 to 800 thousand m^3/year - is used in material applications, the rest is used as fuel.

Of this 20%, 285 to 340 thousand m^3 are processed in Dutch sawmills, together with 110 to 130 thousand m^3 of imported industrial round wood.
On the other hand, approximately 100 thousand m^3 of industrial roundwood is exported to sawmills abroad.
About half of the sawn wood is converted into sawn product, the other half into by-products (chips, sawdust, shavings).

Import of industrial round wood takes place to supplement limited availability on the Dutch market, to take advantage of favourable prices abroad (for example after a storm, as in Germany in 2011) and/or because of shorter transport distances (in the case of sawmills, for example in southern Limburg). Import of tropical roundwood is negligible.

6.7.2 Sawn timber

Most sawn timber consumed in The Netherlands is imported and consists for approximately 90% of coniferous wood, see Table 6.1.

Table 6.1
Balance for sawnwood in The Netherlands (in 1,000 m3), all figures for 2018

	Total	Coniferous	Hardwood	of which tropical
Production	141	90	51	6
Import	3.355	2.989	366	181
Export	767	691	77	29
consumption	2.729	2.388	340	158

More than 90% of the sawn timber and panel material imported in 2018 comes from Europe (95), see Table 6.2. This concerns in particular the import of sawn coniferous wood, sawn moderate hardwoods and panel materials, such as particle board, OSB, MDF and plywood made of coniferous and European deciduous tree species. From tropical regions, tropical hardwood is imported as sawn wood, but also plate material.

Table 6.2
Origins of imported timber and panel board in The Netherlands (in m3), all figures for 2018

	Sawn	Shaved	in 2018
Sweden	273.377	496.499	767.435
Germany	457.649	220.196	683.510
Russia	297.166	102.153	400.887
Belarus	216.031	4.297	220.658
Finland	241.575	42.903	285.347
Latvia	90.024	64.078	153.636
Belgium	103.225	50.612	154.374
Estlonia	28.759	24.745	53.640
Poland	25.658	23.512	49.086
Ukraine	66.637	352	67.235
Other	168.357	99.638	267.571
Total	*1.968.459*	*1.128.985*	*3.103.377*

An overview of the origins of imported sawn tropical hardwood is given in Table 6.3.

Table 6.3
Origins of tropical hardwood, imported into The Netherlands (in m3), all figures for 2018

	Sawn	**Shaved**	**Total in 2018**
Malesia	51.080	44.216	94.936
Brazil	40.227	9.098	49.103
Indonesia	0	46.403	46.403
Cameroon	14.789	75	14.868
Belgium	18.105	4.472	22.541
Germany	4.865	1.594	6.417
Suriname	3.569	542	4.121
Congo	3.805	299	2.722
Chili	120	965	1.090
Guyana	978	49	1.023
Others	7.431	4.463	11.922
Total	*144.970*	*112.176*	*255.147*

Sawnwood not necessarily means wood for construction and for other large products. Sawmills in the Netherlands mainly produce wood for packaging[4] (260 thousand m^3), only some 20% - 25% of the sawn roundwood or approximately 74 thousand m^3 of roundwood from the Netherlands is converted into sawn timber products (96).
It is not clear what this ratio is for imported roundwood.

4 crates, pallets, boxes

6.8 Romania

Figure 6.14 shows an approximate balance for round timber and sawn timber in the Romania. With exception for data on secondary wood products, for which no data was found.

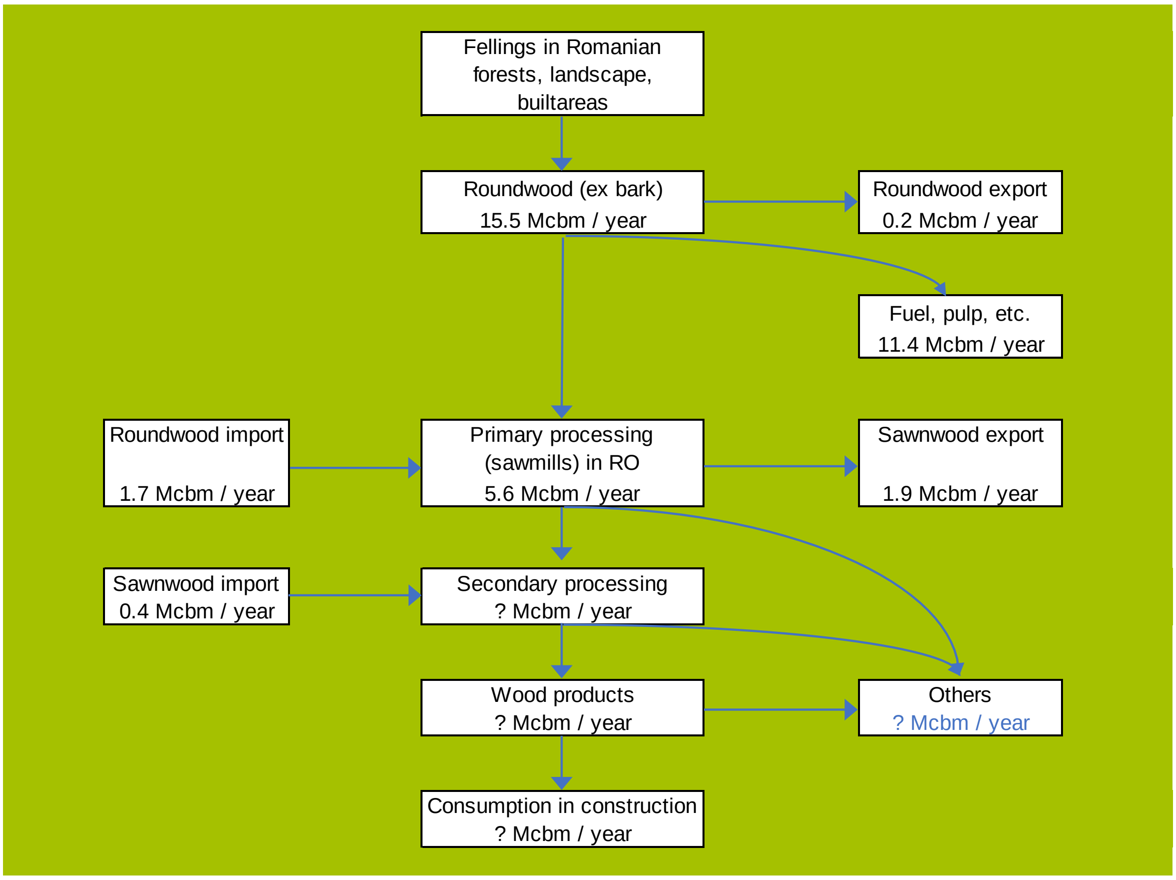


Figure 6.14
Global balance for roundwood in Romania, 2020

6.8.1 Roundwood

Annually, approximately 15.5 million m^3 (under bark) of roundwood and woody material is harvested from forests (80). Almost half (48.8%) of the forests in Romania are owned by the Romanian state, with 33.8% owned by private entities and 17.4% managed by municipalities (97). The standing forest consists mainly of non-coniferous species, such as; beech (39%), oak (14%), and others (97), while coniferous species make up 31% of the stand. This is roughly reflected in the harvested roundwood, which consists of approximately 60% non-coniferous wood and 40% coniferous wood in 2020 (80).

Approximately 36% of the roundwood harvested in Romania is processed in Romanian sawmills. While a large share of wood harvested is used domestically for fuel, seen as about half of Romanian households use wood for heating.
A small fraction of the roundwood harvested in Romania is exported, approximately 160 thousand m^3 per year is exported making up about 1% of total production. A larger amount is imported from mainly neighbouring countries like Ukraine and Poland, with 1.7 million m^3 in 2020 (80). This import-export balance has been stable over the past five years, along with national production.

Import of tropical roundwood is negligible, making up less than a fraction of one percent of total roundwood imports.

6.8.2 Sawn timber

Just under half of the sawnwood produced in Romania is exported, primarily to outside Europe, with 1.9 million m^3 in 2020 (8). Approximately three-quarters of the exported wood is coniferous sawnwood, and a quarter is non-coniferous sawnwood (8), reflecting similar percentages from sawnwood of Romanian sawmills (97). A smaller fraction of sawnwood, about 400,000m^3 per year, is imported, and mostly is coniferous sawnwood. These numbers vary over the years with forestry policy changes and the domestic market minimum price set by the National Forestry Administration (Romsilva) for wood from public forests (97).

No data was found regarding Romanian consumption of sawnwood for the construction elements. Neither centralised databases such as Eurostat or FAO, or the national statistical office (INS) keep records of production and trade volume of secondary wood products. Only economic trade data (import/export) is available, via Eurostat, but leaves too many gaps for any conclusive observations on production and volumes of wood consumed.

6.9 Spain

Figure 6.15 shows an approximate balance for round timber and sawn timber in Spain. With exception for data on secondary wood products, for which no data was found.

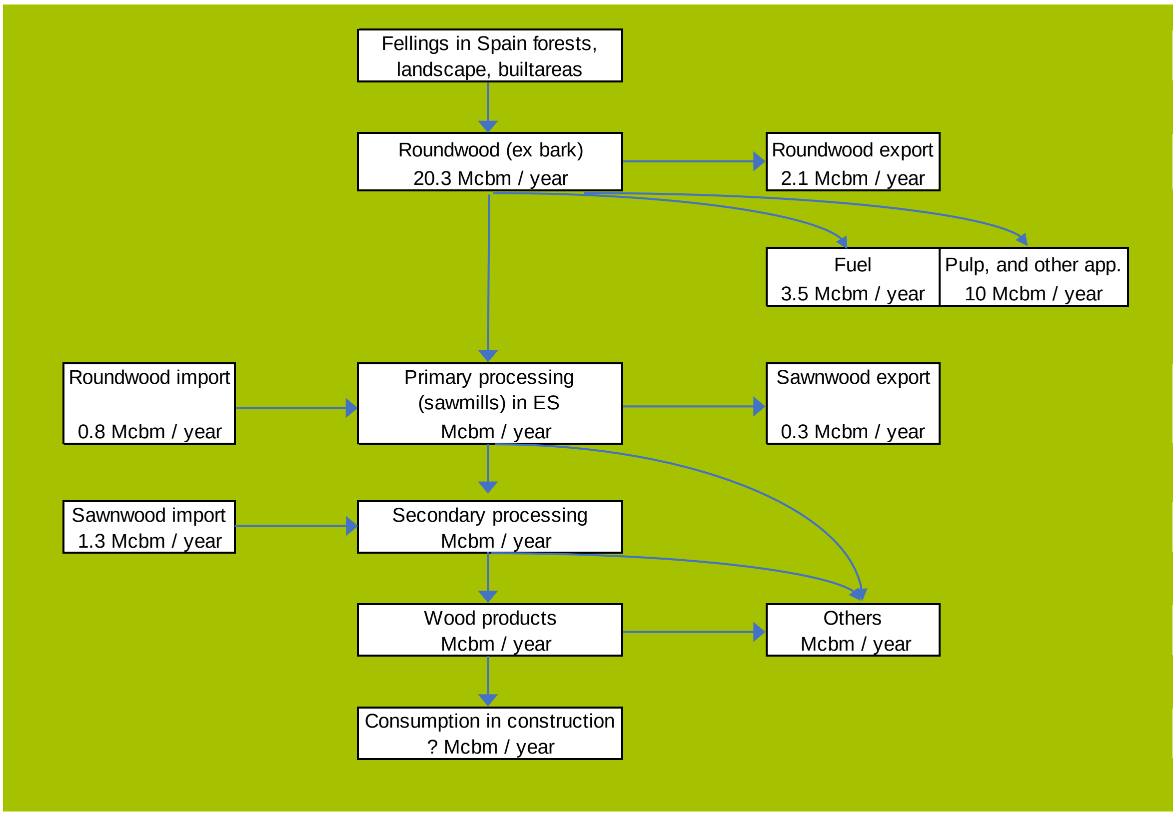


Figure 6.15
Global balance for roundwood in Spain, 2020

The balance is based on data from Eurostat (98) and verified with data from e.g. FAO (2) and the Spanish Department of Agriculture . Due to limited information availability, the assessment for Spain has been summarized in a concise sections without subdivision.

Spain is more or less self-sufficient in terms of wood use by the wood-processing industry - unlike the Netherlands, for example. Import flows are never more than approximately 20% of the total processed volume. Export of round wood is considerably larger than import.

Industrial roundwood extractions consist for approximately 50% of coniferous wood, the other half of non-coniferous wood. The hardwood is largely used as a raw material for pulp production and is probably eucalyptus. saw logs and veneer logs, on the other hand, consist of approximately 80% coniferous wood.
Import of tropical roundwood is negligible.

Scots pine, Salzmann pine, European oak, sweet chestnut and poplar are the most common Spanish grown species used in structures as sawn timber. The most commonly imported species for construction are Norway spruce (Picea abies (L.) Karst.), Scots pine, Larch (Larix spp.), Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) and European oak.

To produce mass timber products, such as Glulam, CLT and Laminated Strand Lumber (LSL), Spanish grown species such as Scots pine and radiata pine, silver fir (Abies alba L.), sweet chestnut and poplar are used

With a volume of approximately 50 thousand m^3/year, the import of tropical wood is more or less negligible compared to the amount of saw logs extracted domestically.

Total imports of secondary products from tropical wood are marginal with a total amount of 1,300 tons in 2019, mainly consisting of mouldings and doors and primarily imported from Brazil, Indonesia and Peru.

6.10 Discussion and conclusions

6.10.1 Overall findings

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. Indicating 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 (99), whilst a large part of the demand for roundwood is for coniferous wood, (although varying per member states and end application).

Overall it remains unclear whether supply and demand of wood in these European member states is 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.

6.10.2 Reflection on the results compared to the "Historic and current local and European supply of timber" results

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.

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7 Process efficiency assessment on waste scenario's

7.1 Introduction

In this chapter, the production and processing of wood waste in the EU is discussed.
The information from this analysis will be used later in the project, among other things, in drawing up greenhouse gas balances for wooden products and in drawing up approximate mass balances for the wood supply chain in the EU and the further deepening of timber supply chains in six yet to be selected Member States (more specifically).

The analysis of production and processing of wood waste in the EU and in particular from the construction and demolition sector is limited to the waste generated in the EU by end users. This concerns, for example, residual flows from:

- the construction sector and from renovation and demolition
- furniture industry
- transport sector and trade (especially packaging waste)
- consumers

Substreams released by these sectors includes very diverse products such as impregnated (preserved) and creosoted wood, wood wool cement plating, moorings and crane mats, crates, pallets, formwork for pouring concrete, doors, window frames, chipboard and particleboard, solid dyed or coated wood, discarded furniture, hardboard, wood piling and timber piles.

7.2 Demarcation

In accordance with the Renewable Energy Directive (RED II), waste is defined as material that the producer (of the waste) must discard of and that is delivered to a waste management facility at a negative price (= costs, gate fee). Residual material is defined in the RED II as material with no (relevant) market value.

The reason for this demarcation and limitation to what is actually the use and disposal phase of the chain of wooden products is that no waste or residual flows are released in the previous chain links (forestry, round wood processing, processing of sawn wood and of by-products).

The assessment in this chapter is based on the premise that everything from the forest is used or is left behind.

- Branch and top wood and stumps are left behind or are harvested as low-grade fuel. Due to relatively high costs, the latter only occurs to a limited extent. Due to the influence on soil quality and biodiversity, utilization as a low-grade fuel is undesirable from a sustainability point of view.

- Bark becomes fuel (called hog fuel in North America)
- Commercial thinnings, sawdust, chips, shavings are by-products with a relevant economic value and are used as raw materials for paper, panel board or energy pellets.

Only wood from the consumption phase can be characterized as waste or residual flow according to the definitions included above.

7.3 Consulted information sources

Several literature sources have been assessed. Of these, FAO provides no figures for waste, only for usable product flows. UNEP is not specific enough as it provides only aggregated waste figures for wood waste, but not broken down by economic sectors such as construction. Pöyry focuses on forestry and semi-finished products, and not so much on waste wood.
Therefore, for estimating the amounts of waste released in the EU and their processing, mainly use has been made of Eurostat data and sector and waste management studies (102 – 109).

7.4 Production

In the EU and the UK, approximately 56 Mtonnes of wood waste are produced annually in the various links of the wooden product chain. This is shown in Figure 71. The numbers in Figure 7.1 refer to as waste collected separately.

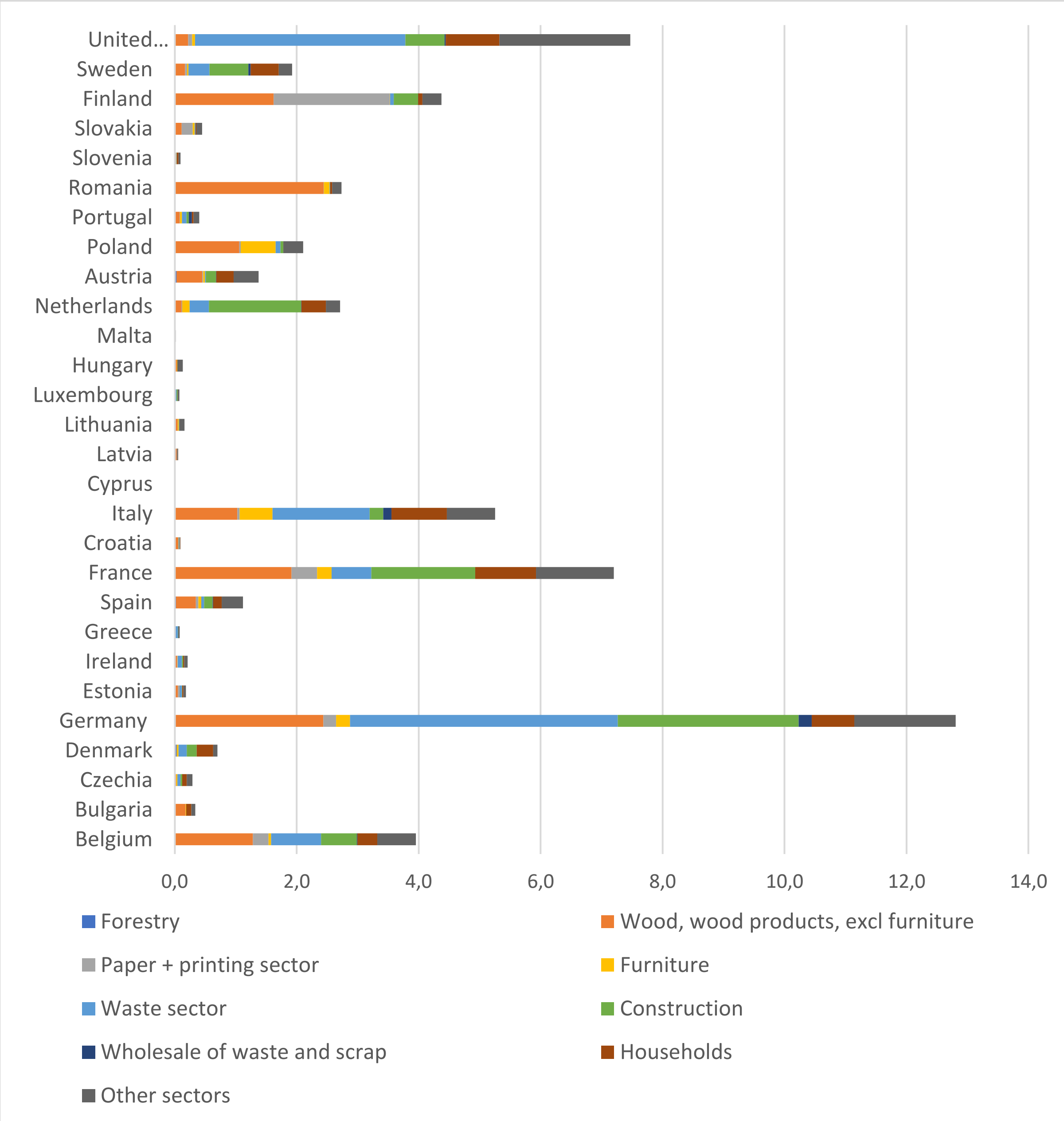

Figure 7.1
Overview of wood waste per member state and per sector for 2018 (all figures in Mtons/year).
Source: Eurostat

Wood waste includes wood-based materials, such as: wood construction, furnishing and packaging wastes, including particle boards, OSB boards, pallets, fruit boxes, packing cases, demolition beams and panels, poles for electric and telephone cables, old furniture and utility items, reels for electric cables, pruning waste, in addition to miscellaneous wood processing wastes (wood chips, sawdust, particle board waste).

Of the total of approximately 56 Mton of wood waste, approximately 9 Mton is produced in the construction sector. As illustrated in the bar chart, this wood waste mainly comes from a limited number of countries. This mainly concerns countries with a large number of inhabitants (Germany, UK, Italy, France). In addition, a significant amount of wood waste is released in the construction sector in The Netherlands.
The waste is released during construction, renovation and demolition.

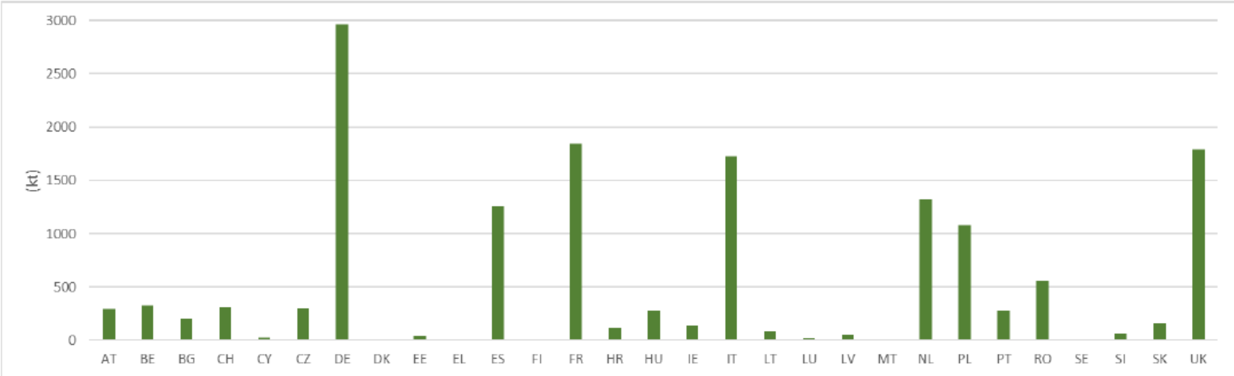

Figure 7.2
Separately provided/collected wood waste from construction sector in 2018 (all figures in kton).
Source: Eurostat

Part of the wood waste released by households (approximately 5 Mton/year) is also related to construction activities. In the Netherlands, approximately 20% of the wood waste released by households comes from construction activities (do-it-yourself).

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.

7.5 Collection and disposal routes

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. A limited part is provided and collected separately.

Isolated wood waste is roughly divided into 3 to 4 quality classes[5]:

- A-grade: Clean and untreated wood;
- B-grade and C-grade: Painted and varnished wood, board materials, etc. – all wood not being A-grade or D-grade. C-grade refers to panel board;
- D-grade: Preserved wood.

B/C-grade wood is a wood fraction that is mainly present in urban-, construction- and demolition waste. The wood fraction consists of all wood, not being: fresh wood, impregnated (preserved), creosoted, wood tar residue, sleepers, rotten wood, charred and burnt wood, wood that has been in water or soil for longer time, wood wool cement plating, moorings and crane mats.
The category includes chipboard and particleboard, solid dyed or coated wood, hardboard, wood piling and timber piles.

Only A-grade and B/C-grade are collected, pre-processed and sold through commercial activities. D-grade wood is processed as hazardous waste through separate channels in recognized and certified installations.

A-grade and B/C-grade wood waste are pre-processed by coarse cleaning is followed by mechanical crushing using special machines that result in roughly chopped wood. Impurities such as nails, screws and other jointing items are removed from these materials, after which the wood is shredded in an even more capillary way. Artificial drying and dry cleaning operations may follow, depending on the requirements down the processing chain. New cutting machines allow minimizing scraps. For more precise removal of impurities near-infrared spectroscopy (NIR) and other more sophisticated technologies may be applied.

Pre-processed wood waste is currently supplied to the following types of outlets (Tosi *et al.* 2019):

- 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 particleboard 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.

A new application that will become operational in the near future will be the use of old wood in steel production. ArcelorMittal is currently building a torrefaction installation in Ghent. Torrefied old

5 See e.g.: http://www.organics-recycling.org.uk/uploads/article2892/Wood%20Briefing_28Aug2014V1%20final.pdf

wood will be pulverized and used as a reducing agent in the blast furnace process. Residual carbon monoxide will be used for ethanol production.

Other, less developed innovative applications for wood residues include fillers or functional fibres in biocomposites, insulation material, pyrolysis and other biorefinery technologies.

The selected sales route of the pre-processed wood depends, among other things, on:
- the quality of the pre-processed material,
- the regional sales opportunities (with or without installations present);
- national policy on reuse and energy production from renewable energy (subsidy regime);
- economic situation (demand for kitchens and other applications of particle board).

7.6 Data concerning collection and processing

The processing of wood waste is shown per Member State in Figure 7.3. At the EU level, the average for 2018 is as follows:
- 490 kilotons was landfilled
- 970 kilotons was incinerated
- 22,800 kilotons was incinerated in dedicated bio-energy plants
- 23,750 kilotons were recycled

This results in an average EU waste scenario for wood products of 49,4 % recycling, 49.5 % incineration and 0,01 % landfilling. In comparison, the current Belgian PCR for EPDs for construction products (NBN/DTD B 08-001:2017), for example, indicates for the waste scenario for B-grade wood 5-15% recycling, 85-95 % incineration, and 0 % landfilling.

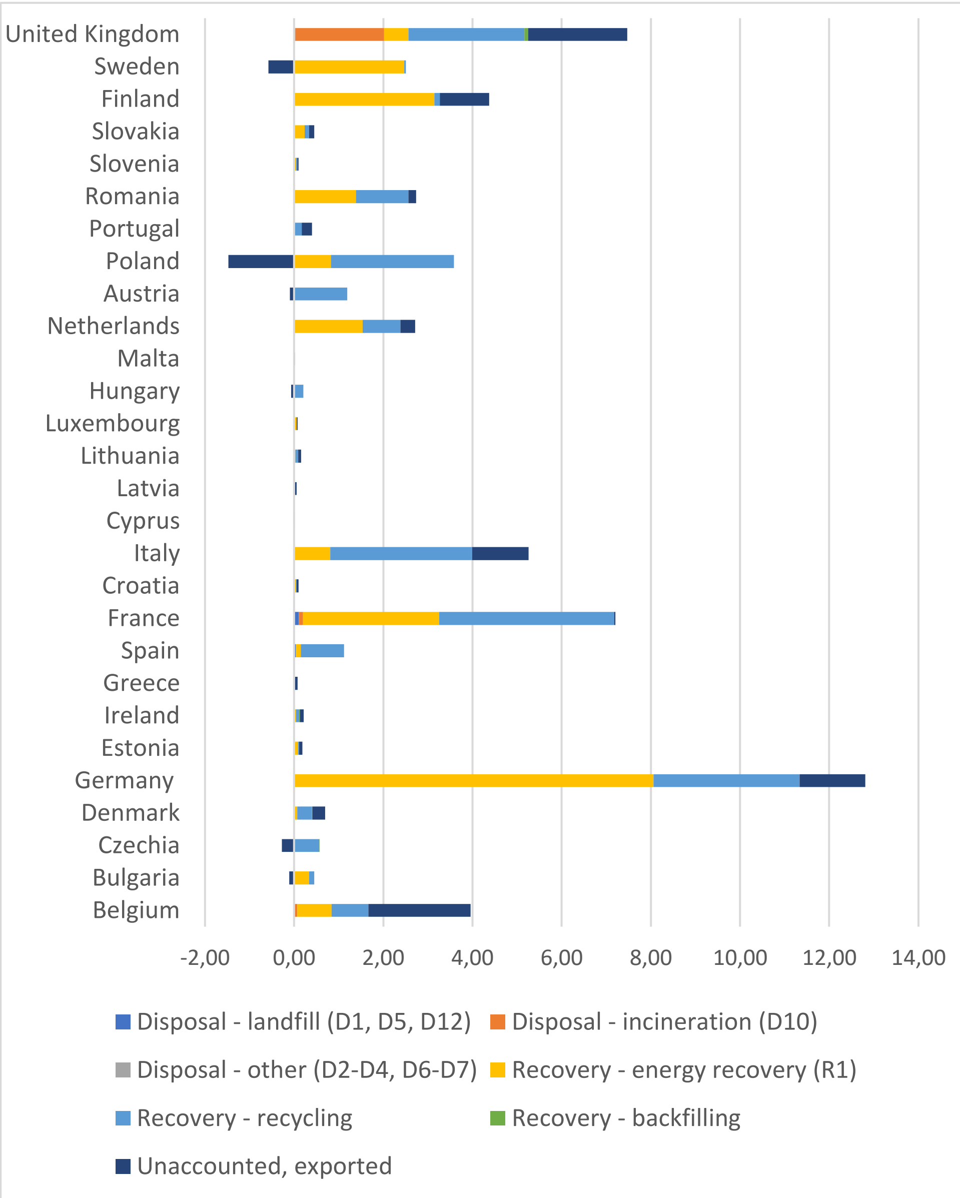

Figure 7.3

Wood waste processing per member state and per type of process in 2018 (all figures in Mton). Source: Eurostat.

Waste treatment and application of pre-processed wood waste is an international business. For example, of the recovered wood processed by the Belgian particleboard industry, only 30% is indicated to stem from Belgium itself. The B-wood bio-energy plant in Delfzijl (NL) imports the majority of the incinerated wood waste from UK, Belgium and Germany. Figure 7.4 provides an overview of the main exporting and importing member states in the EU. Albeit that these data are from 2013 and 2015, it illustrates the international character of the wood waste market for both energy recovery and particle board production.

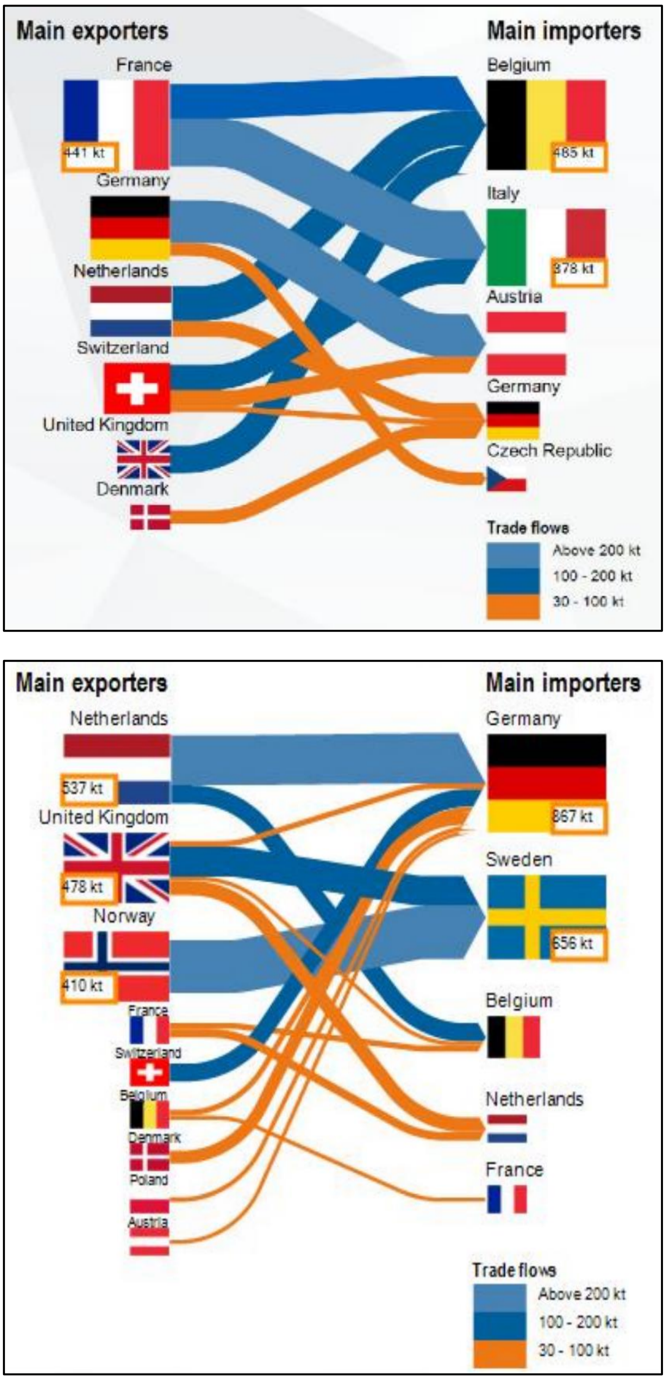

Figure 7.4
Indication of waste wood exports streams for particle board production (top) and energy production (bottom) in the EU (101).

7.7 Particle board production versus 'energy recovery' – competition for resources

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% (Figure 7.5), depending on the regional availability of recovered wood, but also depending on the regional availability of by-products from the wood processing industry.

Total wood demand for particle board in 2014 amounted to:
5.3 million dry tonnes roundwood
7.2 million dry tonnes industry by-products (54% chips & 46% sawdust)
6.0 million dry tonnes recycled wood

In general, the proportion of recovered wood is higher the smaller the regional availability is of (cheaper) by-products. An increasing share of recovered wood in the raw material palette requires a higher use of binder per m^3 of particle board.

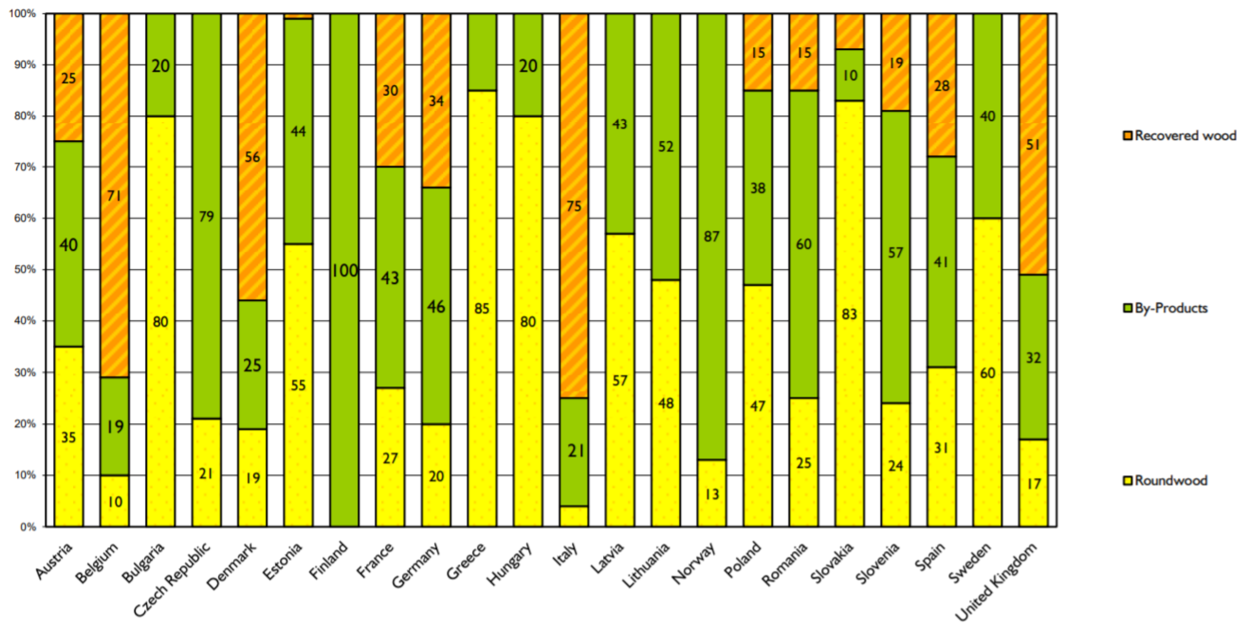

Figure 7.5
Differences in share of the different raw materials in particle board production. (102)

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 to begin with.

Competition is otherwise limited in the EU, given the discrepancy between the production volume of the European particle board industry (10 – 15 Mton/year) and the total amount of residual wood that is released annually in Europe (56 Mton/year). In fact, competition mainly occurs in Northwest Europe due to the modest regional forest cover and the modest size of the wood processing industry on the one hand, and the high demand for particle board in the construction and furniture sectors on the other.

In competition, market prices of waste wood and industrial by-products and the costs for upgrading waste wood to particle board quality (see Annex II) determine whether waste wood is recycled or utilized in 'energy recovery' (104).

The market value of A-grade wood and B-grade wood as raw material for particle board production varies greatly as a function of the economic cycle from – for B-wood – almost zero to a negative price of almost €30/ton (see also Figure 7.6).

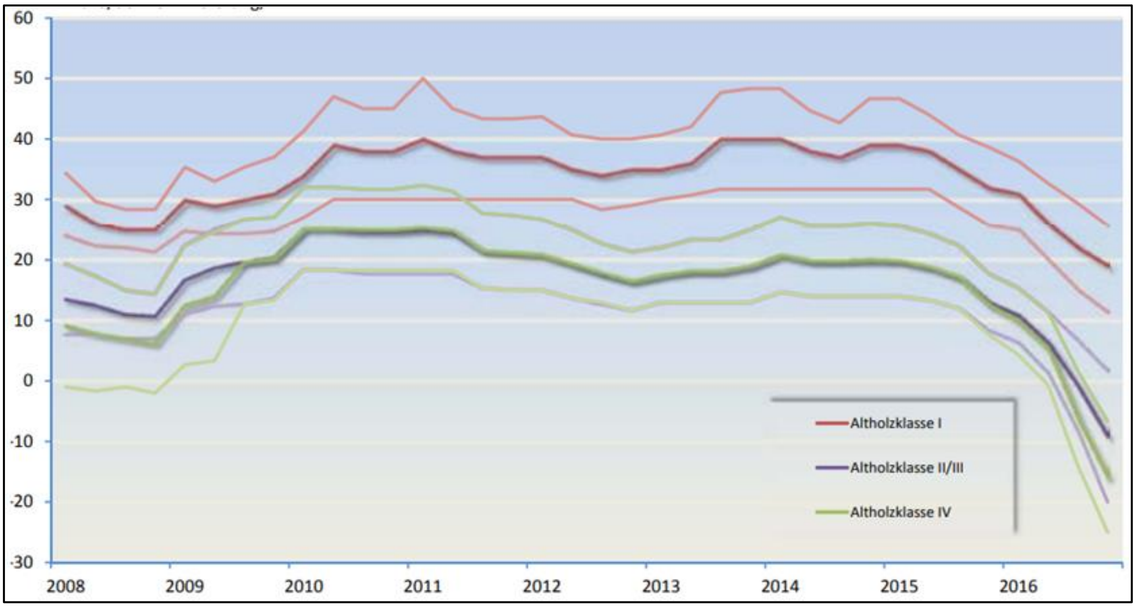

Figure 7.6

Development of residual wood market prices (in €/tonne) in the period 2008 – 2017 (103)

Altholzklasse I = A-grade wood

Other 'klassen' refer to different kinds of B-grade waste wood

Reprocessing of B-grade wood into raw material requires more extensive and therefore more expensive pre-processing, up to €20 - €25 per ton according to Brinkmann, 2014, than reprocessing into fuel (€10 per ton). In addition, delivery to the particle board industry generally may involve longer transport distances.

The consequence of the additional costs in the pre-chain for use in particle board production is that with higher prices for residual wood – as applied in 2016 – and with a sufficiently high subsidy for the use of residual wood as a fuel, the purchasing power of power plants located in the Netherlands and neighbouring countries will out compete the particle board industry. As a consequence, more B-wood is sent to power stations and particle board producers partly fall back on fresh round wood instead of recycled wood (105)(106).

Conversely, current practice with negative prices shows that particle board producers set their purchase price in such a way that it is economically more attractive to sell reprocessed residual wood to them.

7.8 Conclusions on waste scenario's

The assessment of waste scenario's 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.

7.9 References

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8 Assessment on consequential LCA of mass supply of timber

8.1 Introduction

The main motivation to a more biobased economy is to reduce environmental degradation and our dependency on finite resources. Using biobased materials ensures the long term circularity by using natural processes in the natural cycles of e.g. carbon and water. Biobased products are however not necessarily *a priori* environmentally preferable compared to non-biobased alternatives. For example, the transformation of natural forest to managed forests for production can cause biodiversity loss and other environmental degradation. Furthermore, the production of biobased products can be demanding both in terms of non-renewable energy and -resources (111).

The aim of this chapter is to assess current literature on LCA aspects that do not study individual *products*, but study the *consequences* of shifting towards increased use of HWP products.

8.2 Methods

For this part of the study, an overview is given of the principles of life cycle assessment, followed by the main challenges of life cycle assessment in the case of forest products. All available academic publications of comparative life cycle assessment 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. We have summarized the main benefits and the main limitations of consequential LCA. For the literature review on consequential LCA on the topic of mass use of timber in construction, publications from ResearchGate and GoogleScholar were selected based on keywords such as: “consequential LCA, LCA of forest products, mass timber and CLT/GLT” and by cross-checking mentioned work in recent literature reviews.

8.3 Principles of LCA

When considering the best choices for minimizing environmental impact, there is a need for high-quality, context-adapted environmental assessment. For studies of products and services, life cycle assessment (LCA) is the most commonly used assessment tool. LCA is capable of assessing a wide range of environmental impacts over the entire life cycle of a product or service. From the extraction of resources (cradle), via production, transportation and use to waste management and recovery (grave). Although there is a general consensus on the use of LCA and several useful documents guiding a sound LCA (such as ISO 14040/14044, EN16760, ILCD handbook and the PEF guide), it can be rather challenging to carry out a fair assessment on complex products and systems. Key challenges are the modelling of the product system and its interaction with the environment, the translation of emissions and resource use into environmental impacts, and the interpretation in various contexts of use (111)(112). An example of current academic debate is the quantification the environmental benefits of delayed carbon emissions from forest products.

LCA is a widely used and internationally recognised methodology to assess a wide range of environmental aspects over the full life cycle of a product. The method has four distinct steps which are usually carried out in iteration to allow for adjustments following from new insights. These general steps constituting an LCA are:

1. Goal and scope definition
   The aim of the assessment, the functional unit, the product life cycle and the system boundaries are defined. The methodological choices must align with the purpose of the assessment i.e., when comparing products, the whole life cycle must be included and the functional unit must represent shared functionality, e.g.. 1 square meter of surface protected for 10 years. The functional unit accounts for variations in quality or technology.

2. Life cycle inventory analysis (LCI)
   All environmentally relevant material and energy flows between processes and the environment are identified and quantified per functional unit. Flows from the environment to the product system are considered natural resources, whilst flows from the product system to the environment are considered emissions.

3. Life cycle impact assessment (LCIA)
   By means of characterisation the LCI data is translated to potential environmental effects in so called environmental categories. The categories include global environmental effects, such as climate change and stratospheric ozone depletion, but also regional environmental effects, such as eutrophication and (eco)toxicity. There is a large uncertainty that comes with modelling of the more regional impacts than with global impacts, as it is difficult to account for local characteristics. For instance, the exact exposure to a compound highly depends on how and where the compound is emitted. Impact categories can be expected as inventory level, midpoint or endpoint indicators. From inventory level emissions can be expressed as midpoint indicators by normalisation. Different emissions (e.g. CH_4 and CO_2) that contribute to a similar impact category (climate change) are normalised to their contribution, their changed radiative forcing driving climate change. This is often described in equivalents (CO_2-eq). These normalised emissions can be weighed to a single score endpoint indicator using weighing factors. Not all impact categories have equal effect on ecosystems. Weighing can be based on environmental taxes and fees, political goals or calculated environmental damages (environmental costs).

4. Interpretation
   The results of the assessment are interpretated and evaluated, taking into account the goal, scope and LCI (e.g. data gaps and uncertainties). The interpretation often includes a sensitivity analysis in which the influence of critical factors are analysed.

8.4 Challenges of LCA of forest products

Ideally the LCA methodology captures all strengths and weaknesses of forest products. In practise however it is proven difficult to thoroughly assess complex effects of biobased products. Common challenges include: the renewability of forest biomass, biodegradability, carbon neutrality/storage, biodiversity loss and water cycle disturbances and indirect effects (113).

8.4.1 Renewability

The potential renewability of forest biomass is a commonly recognised advantage of forest products compared to conventional products. It is assumed that forest products decreases depletion of abiotic resources and that forest biomass is a renewable resource. This however only holds true if it originates from forests with a constant of growing stock of biomass. Whether this can be claimed depends on the characteristics of the forest (e.g. forestry practises) and the assumptions in modelling of the carbon balance. A sharp rise in the demand for forest products may lead to an overall decrease of forest biomass stock in Europe. When this happens forest products can no longer be considered renewable. As such, whether renewability can be claimed depends on the forest practises in present and future (113).

8.4.2 Biodegradability

Another often mentioned benefit of forest products is its biodegradability, which translates to it not accumulate in nature after disposal. In the end of life phase of products this is often seen as a benefit. However these benefits highly depend on the waste treatment. In the case of anaerobic degradation as a result of landfilling, part of the carbon is emitted in the form of methane (CH_4), a highly potent GHG (113). In the case of incineration it leads to several emissions with environmental impact, such as NO_x, SO_x and PM_x.

8.4.3 Climate change

The most commonly mentioned benefit of forest products is the reduced climate impact. Commonly claimed is that forest products are carbon neutral. This is based on the thought that the biogenic carbon cycle does not contribute to climate change, as carbon uptake compensates for carbon emissions. This however may only hold true with sustainable forest management, as mentioned earlier in the renewability segment (113). Some claims go beyond carbon neutrality arguing that forest products function as a temporary carbon sink with the benefit of reducing total carbon emissions over time. This is however a disputed topic in academia, moreover in the chapter on carbon sequestration.

8.4.4 Biodiversity loss indirect consequential effects

A possible environmental problem of forest products is that its relatively high in land- and water use compared to abiotic resources. Aside from the issue with the renewability of the products, it can also lead to degradation of ecosystem quality and biodiversity loss. As scarcity of land increases, more untouched ecosystems, such as rainforest, are at risk. These consequential effects usually fall beyond the scope of an attributional LCA.

The fact that the main feedstock of a product is forest biomass is not guarantee that it is environmentally superior to non-forest alternatives. Furthermore, the commonly used attributional (comparative) LCA faces several challenges quantifying critical aspects of forest products due to the high complexity of interactions.

8.5 Comparative LCA on the use of timber

There are numerous studies focussed on the comparison of timber to mineral construction materials. The vast majority of these studies conclude that timber in general, and CLT in particular has a lower impact on global warming compared to concrete and/or steel (126-133). For instance, Hart *et al.* (125) evaluated carbon emissions from using steel, reinforced concrete, or engineered timber frame across the building life cycle. They concluded that, over a full life cycle, timber frame engineered buildings had a smaller carbon footprint (119 $kgCO_2eq/m^2$) compared to reinforced concrete (185 $kgCO_2eq/m^2$) and/or steel (228 $kgCO_2eq/m^2$ (125).

The majority of comparative LCA studies were limited to assessing impacts related to climate change without considering the importance of other potential environmental impacts. Thus, potentially overlooking environmental trade-offs that can lead to unintentional shifting of the environmental burdens (125). Furthermore, there is differentiation in the approach of the previously mentioned challenges in assessing biobased products. Some challenges, such as renewability and indirect effects are not addressed in attributional LCA at all. In the following sections different methodologies are assessed that better fit these critical aspects.

8.6 Attributional LCA vs. Consequential LCA

Most life cycle assessment (LCA) 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 system by linking and partitioning unit processes within the system according to a normative rule (i.e. vertical PCR's).

The attributional life cycle inventory modelling principle is a retrospective or descriptive way of modelling. 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. This also applies to the background data, since producer-specific data is preferred (a tier 1 declaration). Averages of generic data are often used when modelling a wide mix of producers or technologies (e.g. when modelling the electricity use). In a consequential 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 8.1 demonstrates the fundamental difference between attributional and consequential LCA.

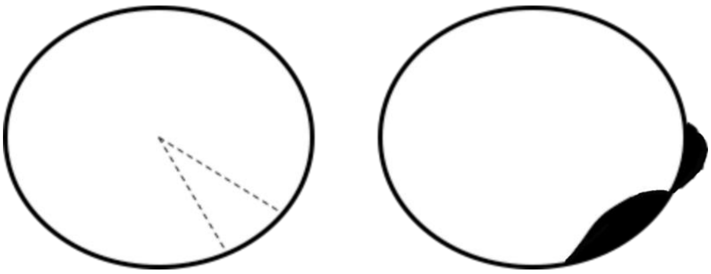

Figure 8.1
The conceptual difference between attributional (left) and consequential (right) LCA (136).

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. As products are secluded from their system their environmental performance can be compared to that of another. Consequential LCA's are used as a decision making tool. It can assess the environmental impacts related to the full share of activities that are expected to change when producing, consuming and disposing of the product.

Consequential LCA can answer policy related questions. It assesses (or should assess) all relevant environmental changes as a result of a policy shift.

8.6.1 Strengths of consequential LCA

Consequential LCA makes it possible to estimate future effects in greater detail. As attributional LCA is based on historical measurable data, it cannot address any future trends. For instance, when comparing forest products with mineral products in an attributional LCA, the smaller production scale of current forest products is disadvantageous as compared to the large scale use of mineral products. In consequential LCA it is possible to address these future trends and advantages of scaling up.
Studies show that consequential LCA has the potential to uncover hidden impacts (137).

8.6.2 Weaknesses of consequential LCA

Although the scenario-driven modelling of consequential LCA makes it possible to estimate future or shifting effects in greater detail, it is worth mentioning that it also comes with drawbacks. We would like to discuss the following drawbacks:

- Assumed substitution
  Most consequential LCA's review a comparative scenario (i.e. quantifying the effects of using more timber in construction). This means that a fair comparison must be made when quantifying the substitution effects. Substitution happens when timber replaces e.g. mineral construction products. The assumptions of substitution must match the functional equivalent in order to accurately calculate the substitution effects. As with all comparative LCA, these assumptions are subject of debate in both academia and industry.

- Uncertainty in scenario's
  Consequential LCA typically uses models to predict future trends (shifts) and scenario's. As such it is possible to quantify long term effects of policy and market changes. These predictions however are often highly uncertain. We argue that in the case of timber products, at least the following subjects should be taken in consideration that have a dynamic aspect as well:
  - Future practises (supply/demand) of forestry and forest products
  - Future impact of the supply chain of forest products
  - Future impact of the supply chain of mineral products used for substitution
  - Future energy mix used for substitution

Reviewing current academic work in consequential LCA on the topic of forest products, we have observed that authors often choose one or two aspects to model dynamically while assuming others to be static. We think this is due to the high degree of uncertainty and complexity. Modelling all mentioned aspects dynamically would lead to a very complex comparison with a very large margin of uncertainty.

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

Despite challenges and the discussed drawbacks, LCA remains the most reliable method of assessing environmental impact of products and comparing products based on this impact. To answer the question whether large scale use of timber can contribute to achieving climate mitigation targets, we argue 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.

We have conducted a state-of-the-art (as of 2000) literature review 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. The literature review of these eight publications is summarised Table 8.1. The last column of Table 8.1 indicates which consequential effects had key contributions to the conclusion of the study.

Table 8.1

Literature review of consequential LCA on the topic of forest products in construction

Title	Authors	Journal	Year of publication	Subject	Geographic boundaries	Conclusion	Substitution conventional construction materials	Substitution at End-of-life	Inclusion of indirect (allocation) effects	Assumed availability of biomass	Key contribution to conclusion
Environmental and economic impacts of substitution between wood products and alternative materials: a review of micro-level analyses from Norway and Sweden	Ann Kristin Petersen Birger Solberg	Forest Policy and Economics	2005	Wood products	NO/SE	Using consequential LCA the authors argue that wood is a better alternative than other materials with regard to GHG emissions. In result of substitution between 36 and 530 kg CO2-eq can be avoided for every m3 input of timber. The variation depends on the EoL scenario and on how carbon fixation on forest land is included.	Static substitution model for steel and concrete	Unknown	Inclusion of carbon fixation on forest land is included, any allocation effects are not	Sustainable forestry assumed (Sweden)	Substitution effects of mineral products
Lifecycle carbon implications of conventional and low-energy multi-storey timber building systems	Ambrose Dodo o, Leif Gustavss on and Roger S athre	Energy Build	2014	Hybrid wood multistorey building (CLT/GLT)	World	Using consequential LCA the authors have looked into the overall carbon balance of timber multi storey building systems, both conventional timber and energy-efficient modern timber. They conclude that significant reduction in carbon emission can be achieved using timber. The carbon balances (full life cycle) of the studies timber building systems range from 113 to 151 kg CO2/m2, compared to 292 kgCO2/m2 for the concrete frame reference building calculated by Dodoo et al.	Static substitution model for steel and concrete	Dynamic model assuming increased landfill with gas recovery, (fossil) substitution assumed	No indirect effects are included. Authors recommend further research on land use	Authors recommend further research on availability and land-use	Substitution effects in energy recovery
Life cycle assessment of construction materials: the influence of assumptions in end-of-life modelling	Gustav Sandin, Greg M. Peters and Magdalena Sva nström	Int. J. Life Cycle Assess.,	2014	Glued laminated timber (GLT) in roof construction	World	Using consequential LCA this study focusses on the comparison of glulam beams and steel frames used in construction. The authors conclude that in comparable scenario's glulam beams have a clear environmental benefit compared to steel frames. Furthermore, the choice of methodological approach (attributional or consequential) did not seem to influence the relative performance of the compared construction elements. What did greatly influence the results was the chosen EoL scenario.	Static substitution model for steel and concrete	Dynamic modelling of EoL scenario's, including the assumption that all EoL processes are excluded (circular economy)	No indirect effects are included.	Sustainable forestry assumed	EoL scenario's

High-rise Timber Buildings as a Climate Change Mitigation Measure - A Comparative LCA of Structural System Alternatives	Julie Lyslo Skullestad, Rolf André Bohne and Jardar Lohne	Energy Procedia	2016	Hybrid wood multistorey building	World	Using consequential LCA the authors claim that the GHG emissions of a timber structure should be considered negative as compared to a building of concrete and steel. This is due to i) offsetting emissions from concrete and steel and ii) by offsetting emissions from energy recovery (assumed to be natural gas in these calculations). Sustainable forestry was assumed. Whether supplies of sustainable timber could meet the demands was out of scope.	The substitution model includes future improvements, such as increased recycling and reduced use of fossil fuels in the best case scenario.	Static model of EoL where incineration is assumed with displacement of natural gas (fossil) in energy recovery	No indirect effects are included.	Sustainable forestry assumed (Norwegian forestry)	Both substitution effects of mineral products and EoL scenario's
Carbon Mitigation Impacts of Increased Softwood Lumber and Structural Panel Use for Nonresidential Construction in the United States	Prakash Nepal, Kenneth E. Skog, David B. McKeever, Richard D. Bergman, Karen L. Abt and Robert C. Abt	For. Prod. J.	2016	Softwood lumber / structural panel	US	Using consequential LCA the authors claim that the GHG emissions from the use of timber (structural and non-structural SW panels) in non-residential buildings in the USA is favourable to conventional (mix of wood, concrete and steel framed buildings). Increased forestry to meet demand was modelled. The calculated displacement factor from the time of writing would be -1,69 tCO2-eq/tCO2-eq as an average for the USA.	Static substitution model for steel and concrete	Static model of EoL where incineration is assumed with displacement of natural gas (fossil) in energy recovery	Inclusion of indirect effects, such as displacement of agriculture	Dynamic modelling of increased demands and forestry operations	Substitution effects of mineral products
How methodological choices affect LCA climate impact results: the case of structural timber	Michele De Rosa, Massimo Pizzol and Jannick Schmidt	Int. J. Life Cycle Assess.,	2018	Timber in construction	World	Consequential LCA in 8 different scenario's and methodological choices on the use of structural timber. The study compares results obtained through different choices concerning four methodological aspects: the modelling of land use change effects, the choice of climate metric for impact assessment, the choice of time horizon and the completeness of the forest carbon stock modelled. In total eight scenario's were tested in the same case study. Annual forest biomass production and degradation was modelled dynamically. The authors conclude that in 7 of 8 scenario's the estimated climate effects were a net carbon emission. In 1 scenario the use of structural timber lead to a carbon sequestration (net negative emission). This study did not take into account the carbon offset of non-wood construction materials.	No offset of non-wood construction materials included	No offset of energy recovery included	Depending on the scenario: land-use changes, carbon storage in soil systems and temporary carbon storage in materials.	Dynamic modelling of increased demands and forestry operations	Carbon sequestration in construction materials, residue's and forest soil
Method for assessing the national implications of environmental impacts from timber buildings, an exemplary study for residential buildings in Germany	Annette Hafner & Sebastian Rueter	W&FS Scientific Articles	2018	Timber products	DE	Using different LCA methods this study estimates the influence of a possible shift from conventional buildings to timber buildings on the national "Greenhouse Gas (GHG) budget', whereby Germany serves as an example. Comparative LCA (15804) on a building level serves as a basis, scaling up to national level dynamically modelling the potential GHG impact of wood consumption,	Static substitution model for steel and concrete	Static model of EoL where incineration is assumed with unknown	No indirect effects are included.	Sustainable forestry assumed	Both substitution effects of mineral products and EoL scenario's

						temporary biogenic carbon storage. In conclusion the authors claim that increasing timber construction can contribute to achieving climate protection targets.		energy substitute			
Linking construction timber carbon storage with land use and forestry management practices	E J Forster, J R Healey, C C Dymond, G Newman, G Davies and D Styles	IOP Conference Series: Earth and Environmental Science	2019	Timber in construction	UK	Using consequential LCA this study focusses on the land-use aspect of mass timber. In total 2 scenario's are calculated: afforestation of 1 ha of grass land to produce timber for construction with i) thinned forest management and ii) unthinned forest management. In these scenario the displacement of mineral construction materials and fossil fuels. The study also looked into the displacement of grass land for the production of beef. It was assumed that these activities would be displaced to Brazil. In result the use of timber in construction has significant abatement potential through both long-term storage of carbon and the displacement of mineral construction materials.	Static substitution model for 1 m^2 concrete block and mortar wall	Static model of EoL where incineration with energy recovery is assumed. Substitution with natural gas (fossil) is assumed	Dynamic modelling of increased demand and the displacement of agriculture	Dynamic modelling of increased demands and forestry operations in the UK	Temporary storage of carbon and substitution effects of mineral products

Comparative life cycle assessment of cross laminated timber building and concrete building with special focus on biogenic carbon	Julie Hansted Andersen Nana Lin Rasmussen Morten Walbech Ryberg	Energy and Buildings	2022	Timber (CLT) in buildings	World	Using comparative LCA this study compares two similar mid-rise apartment buildings applying either concrete or CLT as the main structural material. Special attention is given to biogenic carbon. In conclusion CLT had the lowest impact score in 11/18 impact categories. For climate change CLT had a much smaller contribution than the mineral alternatives (454 kg CO_2-eq vs 904 kg in the base scenario and a much smaller contribution (289 kg CO_2-eq/m^2 vs 893 kg) in the biogenic carbon scenario. When projecting the need for forest transformation, the authors concluded that for new buildings in 2060 about 3% of the current global forest area would be needed (47,5 m^2 per m^2 building area).	No substitution effect applied, comparative approach. The consequential aspect stems from the assessment of increased forest transformation	Static model of EoL where incineration and recycling is assumed. Energy recovery is unknown	No indirect effects included	Estimations for land use without the inclusion of displacement or deforestation	Temporary storage of carbon

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 significant 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 EoL was modelled, some studies assumed fossil energy carriers to be displaced, assuming energy use to be statically (113) (114). 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. One recent study considered a sharp rise in demand within the geographical boundaries of the study and assumed agricultural activities, such as the production of beef to be displaced to Brazil (28). Despite these negative side-effects, the authors concluded that the increased use of timber in construction still has significant abatement effects.

Although the results from the reviewed consequential LCA's of timber used in construction show an overall potential of reduced carbon (GHG) emissions, several impacts need to be considered. The first impact that needs to be considered concerns land use requirement for increased timber production. Emissions associated with natural processes of growth and decay in the forest are not included in most LCA. The significance of this is, as of yet, not well understood.
In extension of this: there is question of whether sufficient land is available. Evidence suggests that Europe may not be able to meet demand for rapidly growing timber use from its own forests, at least not far beyond the current *apparent* balance of supply and demand (see Chapter 2). As a consequence of meeting this demand, the consumption of alternatives with high environmental life cycle impacts, such as tropical timber or synthetic materials, will inevitably increase.

Another impact that needs to be considered is the temporary storage of carbon in wood products. There is ongoing academic and regulatory debate on whether wood products should receive some credit for the temporary carbon storage service provided. As of yet, there is no consensus on how to apply this correctly.

Lastly, the potential impacts of the end-of-life (EoL) scenario's vary greatly among the reviewed consequential LCA studies. Some studies assume that forest products end up in landfills, where carbon is partially stored in the long term. In Europe, such EoL scenarios are less and less likely within the regulatory context (the Waste Framework Directive of 2008).
Other studies suggest that most forest products end up in waste incineration facilities, where energy is recovered and alternative energy sources are displaced.

Furthermore, most scenario's used are considered static, while most are very dynamic in the typical time-frame of construction products. Some dynamic aspects in EoL are: future landfill availability, biodegradation and landfill gas production rates, energy recovery efficiency and the carbon intensity of future energy mix. For example, several studies assumed the displacement of natural gas when energy is recovered in EoL. This however does not consider the expected decarbonisation of the energy mix by the time EoL is reached (115) (125). Similarly, it is expected that future EoL solutions may also include more re-use and recycling, or novel technologies such as biochar, in which carbon is stored in the long term.

8.7.1 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 dominating 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.

In section 8.5, on the subject of comparative LCA, examples of carbon footprint LCA calculations for wood-, steel- and concrete framed buildings were given, with the lowest carbon footprint for wood, then concrete, and then steel. Although a comparative LCA, here too, important specifics of materialisation and documentation of model parameters are not part of the publication, making the bottom line results more 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, two recent studies (139) (140) show that choices pertaining to specific type of construction material (both for wood products and concrete products), and building structure and morphology (i.e. low-rise, multi-story, and high-rise) greatly influence the outcome of LCA calculations in terms of GHG emissions: different qualities of wood (especially in terms of preservation and maintenance) and concrete (especially in terms of binders and secondary materials) can make the difference in which type results in higher GHG emissions (139). Similarly, structure and morphology can make the difference whether the design of the building made mostly out of wood or mineral products result in higher GHG emissions: for buildings in Trondheim and Kristiansand up to 4 stories, designs with wood construction resulted in lower GHG emission, whereas from 8 stories and up, constructions with optimised concrete composition (in terms of binders and aggregates) have a smaller carbon footprint (140).

In a more general sense, Harmon (141) performed a sensitivity analysis of the key assumptions in product substitution of wood for more fossil carbon intensive building materials which suppose significant climate mitigation benefits (141). 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 studies clearly underline the importance of the assumptions and starting points for substitution effects in consequential LCA's.

8.8 Conclusions

The 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 emission. 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. The choice between attributional and consequential approaches should be treated carefully. It has been recommended earlier that several fundamentally different scenarios are needed when modelling future disposal processes, particularly if a consequential approach with substitution is applied (135).

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.

At the time of writing this report, IPCC's Working Group III (Mitigation of Climate Change) is finalising its 6th Assessment Report. The draft of this report (142), although dedicating sections on bioeconomy and carbon storage, does not provide a scientific consensus on temporary carbon storage in construction materials and how to account for benefits and contribution to climate change mitigation, or comparison with mineral construction products. The reported background scientific base appears to show the same ambiguity when considering substitution effects.

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9 LCA database analyses and EPD assessment of GHG emissions

9.1 Introduction

As part of the review of Life Cycle Assessment (LCA) methods of biobased construction materials, a review is performed on LCA background databases. 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 (Figure 9.1) and of processes up and down the product value chain.

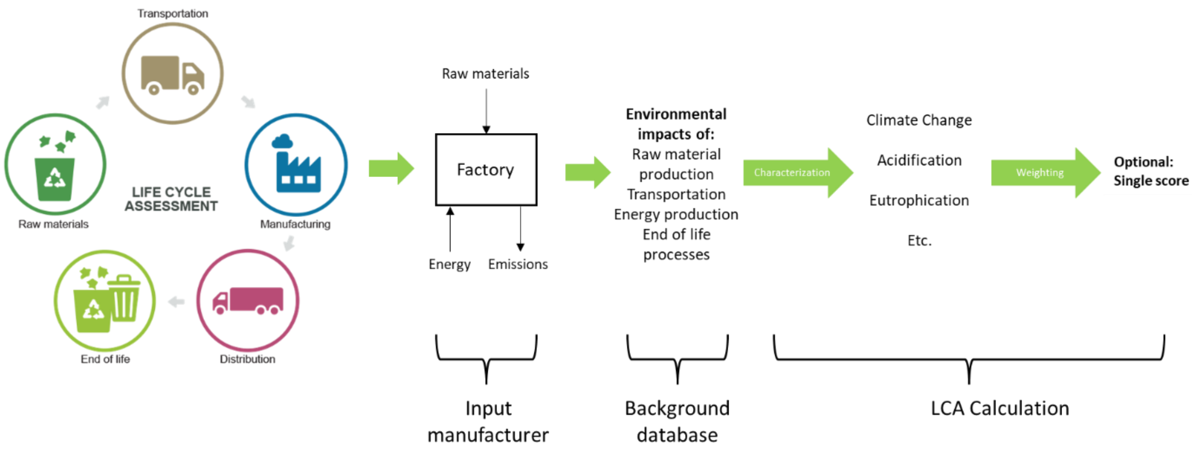


Figure 9.1
LCA calculation steps

A background model in, for example, the Ecoinvent background database has the following structure (Figure 9.2):

- Inputs – Natural resources
- Inputs – From technosphere, connecting to other background models
- Outputs – 1 unit of product, which can form the input of other background models
- Outputs – Emissions and waste

According to EN 15804+A2, the system boundary between nature and the technosphere is defined as *"the point when material transfers from natural systems to the technosphere (i.e. when material flows are caused or influenced by human technological activity) and when emissions are released from the technosphere to nature. The studied system should therefore include all processes in the technosphere which are necessary to provide the functional or declared unit of the product"* (143). This definition is generally applied in the background modelling of Ecoinvent.

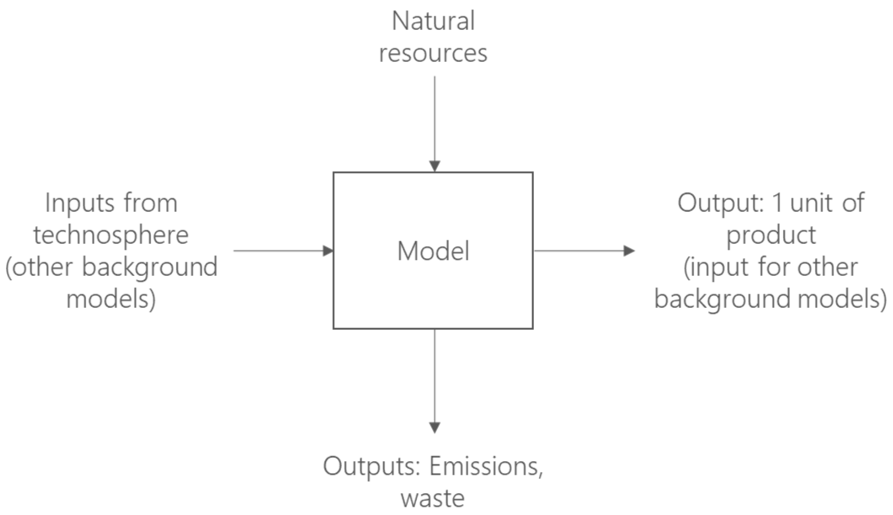


Figure 9.2
Schematic overview of background model

Due to the large number of biobased construction materials and background datasets, the focus of this review is set on two important construction materials: beams and panels, both solid and composites, and made of hard wood and soft wood (see Figure 9.3). Analysed composites include Cross-Laminated Timber (CLT), Glued laminated timber (Glulam), hard fibreboard and Medium-density fibreboard (MDF).

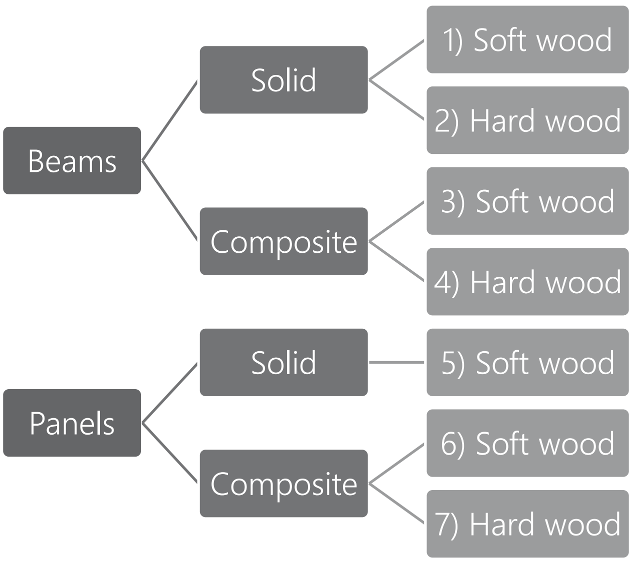


Figure 9.3
Reviewed products in LCA background databases

The geographical scope of this review is set on Europe, with outlook to other regions where relevant. Efficiency of biobased production processes (forestry, sawing, planing) in background modelling is compared to recent statistics, namely the Forest Product Conversion Factors report (144), An initiative from the UN and International Tropical Timber Organization. Special attention is put on underlying modelling assumptions of sustainable forest management and biogenic carbon balancing.

In the remainder of section 9.1, a description of the main LCA background databases used for construction products is given. Furthermore, an introduction is provided into data accuracy, modelling choices and allocation methods. In section 9.2, an extensive analysis is provided of the Ecoinvent database, including an overview of main modelling approaches for biobased construction products and comparison with reference data. Section 9.3, an assessment is made of the Gabi background database. Lastly section 9.4 features an assessment of environmental product declarations (EPDs) of wood products.

9.1.1 LCA background databases in use

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 (including EU and countries like Switzerland, UK and Norway): Ecoinvent and Gabi. These databases are investigated in this chapter.

The origins of both databases are shortly discussed below, followed by a short discussion on other databases.

9.1.1.1 Ecoinvent

The Ecoinvent database finds its origin in Switzerland in the late 1990s. It covers a diverse range of sectors on global and regional level. It currently contains more than 18,000 activities, otherwise referred to as 'datasets', modelling processes and human activities. Ecoinvent datasets contain information on the industrial or agricultural process they model, measuring firstly the emissions released to water, soil and air, and the natural resources withdrawn from the environment. They also contain inputs from other products and energy and co-products and wastes produced.

Each activity in the Ecoinvent database is tagged with a geographic location. As the Ecoinvent database is a global background database, it aims to cover activities in the most relevant regions for the selected product or service. At the same time, geographic coverage is dependent on data quality and availability. Therefore, almost every activity in the database features a dataset representing the process globally, meaning the average global production. As Ecoinvent is originally a Swiss database, there is a relatively large number of datasets tailored to Switzerland (145).

The LCA database analysis is focused on Ecoinvent 3.8, as this is the most up-to-date release that will be used in the coming years. Recent updates include changes to datasets related to forestry activities and wood processing in the Forestry and Wood sector (3.7 - released in 2020) and changes to biogenic carbon allocation in order to better track biogenic carbon through product value chains (3.8, released in 2021). Lastly, Ecoinvent 3.8 features a database version that adheres more strictly to the allocation principles laid out in the construction sector LCA standard EN15804 (146) (147).

9.1.1.2 Gabi

The Gabi database originates in Germany and has been developed for the last 30 years. It is currently owned by a US based multinational organization (Sphera) with more than 200 life cycle experts from over 20 countries contributing to the development of GaBi Databases. All LCI datasets are generated in compliance with the ISO 14044, ISO 14064 and ISO 14025 standards.

The Gabi databases cover over 15,000 plans and processes, to a large extent based on primary data collection from companies, associations and public bodies. It includes 2,300 datasets that are available as "Data-on-Demand only" content. It is claimed that GaBi Databases have by far the largest LCI data industry coverage worldwide. Sphera also offers its own software toolset for LCA calculations, also integrating with other databases (148).

9.1.1.3 Other databases

The European Commission has done a number of initiatives concerning LCA background databases, motivated by its ambitions on sustainability and fair competition. Standardization is also a very important topic for the EC, such as the ISO framework starting with ISO 14040 and 14044 standards, and subsequently resulting in CEN standards EN 15804 and EN 15978. This framework leaves the individual experts, practitioners and data developers, however with a range of important choices that can be individually interpreted. This can lead to differences in consistency, reliability and comparability of assessment results. Equally, the methodological assumptions behind the background data can differ widely, so that data from different sources can be not used together. The International Reference Life Cycle Data System (ILCD) is an initiative developed by JRC and DG ENV, with the aim to provide guidance for greater consistency and quality assurance in applying LCA and use of background databases (149).

Until 2018 the EC had its own database initiative, the European reference Life Cycle Database which is now discontinued. Individual data providers that were included in that database continue to offer their services and share the data through the Life Cycle Data Network (LCDN), supported by the EC (150).

To follow up on this initiative, the Environmental Footprint (EF) database was created, facilitated by the European Commission and designed to support the implementation of Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) studies. It contains the official secondary EF-compliant life cycle inventory datasets and the compatible EF impact assessment methods for a large number of sectors. The database encourages industries to provide data themselves, for example through industry associations. The Environmental Footprint development is part of the European Commission's Single Market for Green Products Initiative. Version 3.0 is currently under development (151). It is important to realise however, that the ILCD and also the EF database datasets are for an important part derived from other established background databases such as Ecoinvent or Gabi.

EXIOBASE is a free to use database, describing itself as a global, detailed *Multi-Regional Environmentally Extended Supply-Use Table* (MR-SUT) and *Input-Output Table* (MR-IOT). In essence, this is similar to other LCA-databases. It was developed by harmonizing and detailing supply-use tables for a large number of countries, estimating emissions and resource extractions by industry. Subsequently the country supply-use tables were linked via trade creating the MR-SUT and MR-IOT. The tables can be used for the analysis of the environmental impacts associated with the final consumption of product groups. Application of this database for LCA calculations of construction products is limited so far (152).

9.1.2 Data quality of LCA background databases

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. This changes and increases accuracy of the LCA-results. Additionally, supply ratios between regions are regularly reviewed, including transport modes and distances, thereby keeping the datasets that encompass larger regions more accurate.

Updates do cause a significant lag in application of the newest scientific insight to LCA calculation and EPDs, as it can take a few years before databases reflect new insights and again a few years before new database releases are widely used. Currently, the newest version of the database is Ecoinvent 3.8, released in 2021. Earlier versions of the database are still in use. For example, the Dutch PCR currently requires the use of Ecoinvent 3.6, released in 2019 (153).

Most databases include comprehensive background information, in which data origin, methodology, data reference period, updates and data sources are provided.

9.1.3 Allocation methods

Allocation is defined as partitioning the input and/or output flows of a process to the product system under study. This is complicated in cases where processes have multiple outputs and input and/or output flows cannot be assigned to specific (co-)products.

The basic methodology for (economic) allocation in LCAs is dealt with in ISO 14041: "Where physical relationship (i.e. kg, m^2, m^3, etc.) cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way which reflects other relationships between them. For example, environmental input and output data might be allocated between co-products in proportion to the economic value of the products ". In most cases, including European standard EN 15804, economic allocation is advised as baseline method for most allocation situations in a detailed LCA (154).

9.2 Ecoinvent database analysis

For the analysis of the Ecoinvent background database, version 3.8 is observed (147), of which the *allocation, cut-off by classification (unit)* library is selected. This library is commonly used when performing LCA-calculations for construction products according to the EN 15804 standard. A specific '*EN 15804*' library is also made available by Ecoinvent at the time of writing this report, which will be the new standard library in building product LCA. However, this library is not yet available in the calculation programme (Simapro) and therefore not used in the calculations for this section. It has specific updates to the additional parameters describing resource use and waste and correct application of the end of waste boundaries as described by EN 15804. For a few background models, summarized results found in the Ecoinvent online environment for the *EN 15804* library have been compared to results of the *allocation, cut-off by classification* library from Simapro. This indicated slight deviations in GWP-results that stay well below 1%. Therefore, the analysis provided here of the *allocation, cut-off by classification (unit)* library is also deemed representative for the new *EN 15804* library.

In the following sections, the modelling steps are discussed in terms of accurate representation, conversion efficiencies, methodology and data quality, particularly pertaining to biogenic CO_2. Additionally, the background processes that make up the value chain in LCA modelling, have also 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 (Annex III shows the extent of the network for 1 m^3 of CLT). Obvious omissions were not identified.

9.2.1 Solid wood product modelling

In the Ecoinvent database, modelling of most wood products follows a similar approach. For the solid wood products analysed (beam and board, for both soft- and hardwood), the production steps are modelled as shown in Figure 9.4. Four steps are identified: forest (forestry), sawmill, dry kiln or yard and planing mill, which are modelled separately. In reality it differs whether these activities are located together or not. The standard model for *sawn wood, dried, planed*, average transport modes and distances are modelled between forest and sawmill, suggesting the activities of sawing, drying and planing are located together. A LCA practitioner can (and usually will) adjust background and transport modelling to reflect the actual situation, thereby also accurately modelling more transport (if present) between production steps.

In the forestry modelling, inputs and outputs can be separated between different outputs, so no allocation is necessary. In the sawmill and planing mill, economic allocation is applied. In the latest Ecoinvent database (version 3.8), a biogenic carbon resource correction is applied, in order to accurately track biogenic carbon through the value chain. In essence, biogenic carbon is allocated based on mass, not economic values. This is in compliance with EN 15804, in which it is specified that inherent properties of materials are not subject to economic allocation. This has become more relevant with introduction of the newest directives of EN 15804+A2 (2019) on reporting of biogenic carbon content (143), which is likely the reason for the adaptation in the newest Ecoinvent version. As is shown in section 9.4, the resource correction parameter is not yet applied in the appropriate LCA calculation methods to be used together with Ecoinvent for characterization of construction products. Biogenic carbon should therefore be considered carefully (and calculated manually based on final wood product properties) by an LCA practitioner.

The different modelling steps are explained in more detail below.

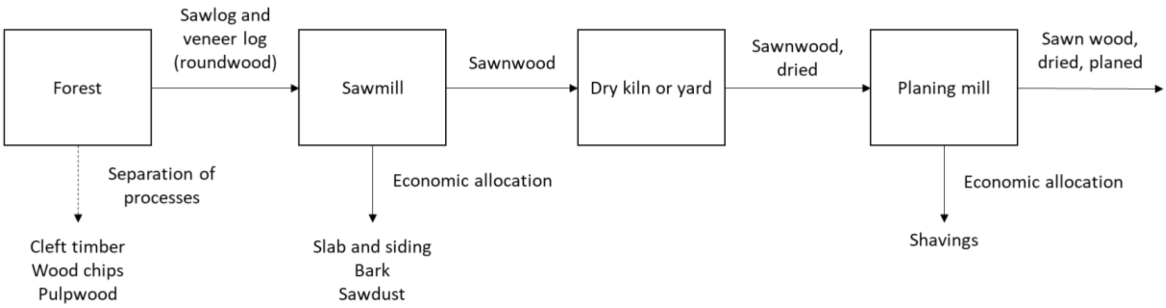


Figure 9.4
Value chain of background processes for solid beam and board in Ecoinvent

9.2.1.1 Forest
This modelling step includes forestry processes that result into four different products: sawlog and veneer log, cleft timber, wood chips and pulpwood. These are specifically modelled for several wood species, such as pine and spruce (softwood) and beech, oak and birch (hardwood). The inputs and outputs of forestry processes are directly assigned to a specific product, so no allocation is necessary. An example of forestry modelling for pine in Germany is shown in Table 9.1, which shows the expected inputs, such as CO_2-uptake, machinery and fuel use, land transformations (characterized to LULUC). In the background modelling, both wood production from thinning and final harvest is taken into account, with the production from thinning varying from 23% (Beech) to 39% (Oak).

Cleft timber and wood chips are modelled per kg dry mass, as opposed to pulpwood and sawlog that are modelled per m^3. However, when scaled to the same unit (using the appropriate dry wood density of 490 kg/m^3), it is shown that impacts are very similar except for clefting (only for cleft timber) and diesel use.

Two things stand out when observing forestry modelling in Ecoinvent for the selected products:

- All hardwood and softwood forestry processes are characterized as 'sustainable forest management'. No models exist that are either characterized as non-sustainable forest management or that do not have the sustainable distinction.
- Second, all biogenic carbon uptake in these forestry models is directly 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, including above-ground components (tree tops, branches, twigs, foliage, sometimes stumps) and below-ground components (roots). Additionally, there is no mention of change in carbon bound in soil. This implies that either the carbon neutrality principle is applied in the model, meaning that these emissions are compensated for, 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 of the modelling principle behind sustainable forest management. The definition of sustainable forest management that is used by Ecoinvent seems to originate from the Ecoinvent 2 database. In the background documentation it is indicated that the distinction 'sustainable forest management' is derived from forestry legislation in Germany and Switzerland. Sustainable management of forest is also described as: *'the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems* (155). This indicates that the term sustainable forest management as defined by Ecoinvent does not also or specifically include the principle of carbon neutrality.

When observing Table 9.1, some of the modelling inputs seem to support the sustainable forest management principle, including the planting of new tree seedlings and equal transformation from and to forest area. However, as all models within Ecoinvent have this characterization, it is not possible to observe non-sustainable modelling.

Table 9.1
Overview of calculated impacts for four products in softwood forestry, pine, Germany, sustainable forest management (Cut-off, U, Ecoinvent 3.8)

	Unit	Cleft timber, measured as dry mass (per kg)	Wood chips, wet, measured as dry mass (per kg)	Pulpwood, softwood, measured as solid wood under bark (per m^3)	Sawlog and veneer log, softwood, measured as solid wood under bark (per m^3)
Inputs from nature					
Carbon dioxide, in air	Kg	1,81E+00	1,81E+00	8,88E+02	8,88E+02
Energy, gross calorific value, in biomass	MJ	2,04E+01	2,04E+01	1,00E+04	1,00E+04
Wood, soft, standing	m^3	2,04E-03	2,04E-03	1,00E+00	1,00E+00
Occupation, forest, intensive	m^2a	3,12E+00	3,12E+00	1,53E+03	1,53E+03
Occupation, traffic area, rail/road embankment	m^2	6,89E-02	6,89E-02	3,38E+01	3,38E+01
Transformation, from forest, intensive	m^2	2,60E-02	2,60E-02	1,27E+01	1,27E+01
Transformation, from traffic area, rail/road embankment	m^2	5,74E-04	5,74E-04	2,81E-01	2,81E-01
Transformation, to forest, intensive	m^2	2,60E-02	2,60E-02	1,27E+01	1,27E+01
Transformation, to traffic area, rail/road embankment	m^2	5,74E-04	5,74E-04	2,81E-01	2,81E-01
Inputs from technosphere					
Clefting of energy wood {RER}| clefting/splitting of energy wood | Cut-off, U	hr	6,17E-04			
Forwarding, forwarder {RER}| forwarding, forwarder | Cut-off, U	hr	5,31E-05	5,31E-05	2,60E-02	2,60E-02
Gravel, crushed {RoW}| market for gravel, crushed | Cut-off, U	kg	2,20E-01	2,20E-01	1,08E+02	1,08E+02
Harvesting, forestry harvester {RER}| harvesting, forestry harvester | Cut-off, U	hr	3,98E-05	3,98E-05	1,95E-02	1,95E-02
Power sawing, without catalytic converter {RER}| processing | Cut-off, U	hr	9,45E-04	9,45E-04	4,63E-01	4,63E-01
Skidding, skidder {RER}| skidding, skidder | Cut-off, U	hr	1,38E-04	1,35E-04	6,77E-02	6,77E-02
Tree seedling, for planting {RER}| tree seedling production, in unheated greenhouse | Cut-off, U	p	2,13E-02	2,13E-02	1,04E+01	1,04E+01
Diesel, burned in building machine {GLO}| market for | Cut-off, U	MJ	2,87E-02	2,87E-02	1,41E+01	1,93E+01

9.2.1.2 Sawmill

The sawmill process transforms the sawlog under bark into sawn wood in various forms such as laths, board or beam and a number of by-products: bark chips, sawdust, wood chips and slabs and sidings (Figure 9.5). Here, it is not possible to separate inputs and outputs, so economic allocation is applied. As described above, a 'resource correction' for biogenic carbon is applied with Ecoinvent 3.8, thereby allocating the appropriate amount of biogenic carbon to the by-products based on physical properties (dry wood density). This means that relatively more biogenic carbon is allocated to low value by-products in comparison to other impacts such as fuel consumption.

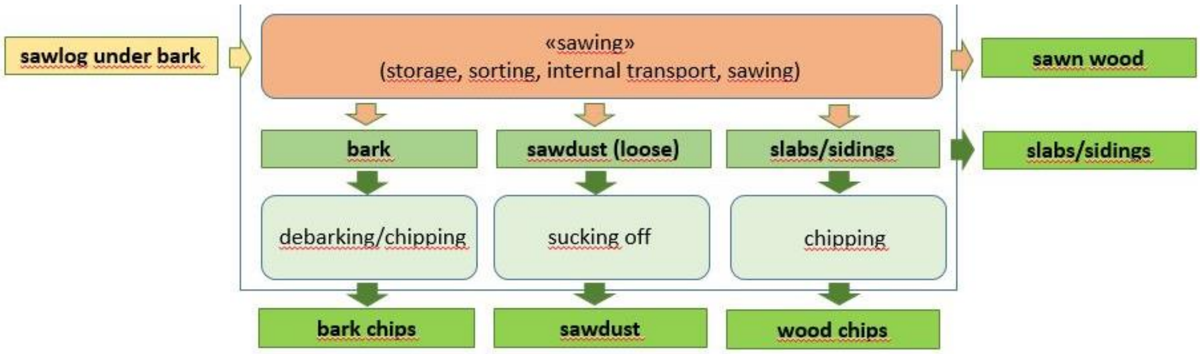


Figure 9.5
Structure of sawmilling process in Ecoinvent (156)

9.2.1.3 Dry kiln or yard
In the dry kiln or yard, sawn wood is dried to reach a lower moisture content. Models are provided for moisture content levels of either u=10% or u=20%. Drying is done with a dry kiln, requiring a fuel input, or by unaided drying in a yard. Fuel for the kiln is typically modelled as wood chips.

9.2.1.4 Planing mill
The planing mill converts the dried wood to a final product, such as a beam or a board. This process creates shavings, a by-product for which again economic allocation needs to be applied. Again, a 'resource correction' for biogenic carbon is applied.

9.2.2 Composite wood product modelling

Modelling of composite, or engineered wood products exists in two categories. Firstly, modelling of laminated timber elements, such as cross-laminated timber (CLT) and glued laminated timber (Glulam) is very similar to solid wood products. They are made out of (dried) sawn wood, where adding of binders and fillers is the most significant addition to the value chain of solid wood products. Background models of composite wood products made out of particles or fibres are modelled differently, there the input is mostly pulpwood and wood chips, combined with adhesives.

It should be noted that for both solid and composite products, the modelling can be adjusted by a LCA practitioner to reflect an actual manufacturer's situation. Additionally, all wood inputs for composite wood products observed (both beam and board) are also designated as to originate from sustainable forest management.

Both types of composite wood product modelling are discussed below.

9.2.2.1 Laminated timber elements

For modelling of laminated timber elements, the production steps are modelled as shown in Figure 9.6. For part of the wood input, similar modelling steps are identified in comparison to solid wood products: forest (forestry), sawmill and dry kiln or yard, after which the product is finished in a composite factory. However, some of the wood input in the standard production model is input from sawn wood and sawlog directly from forestry. This implies that there is a portion of the manufacturers that combine the activities of sawmilling, drying and manufacturing of composites and that this is included in the modelling to reflect market averages. This is different from the modelling of solid wood products, where each step is modelled completely separate. A reason for this might be that these models are simply newer than the original solid wood product modelling, and at the time of creation a choice was made to take an alternative modelling approach.

Of both CLT and Glulam modelling only a version with softwood input is included in Ecoinvent. Related product models, such as 'laminated timber element, transversally prestressed, for outdoor use', a small portion of hardwood input is included. The modelling indicates a common industry practice to use mostly softwood for these type of products.

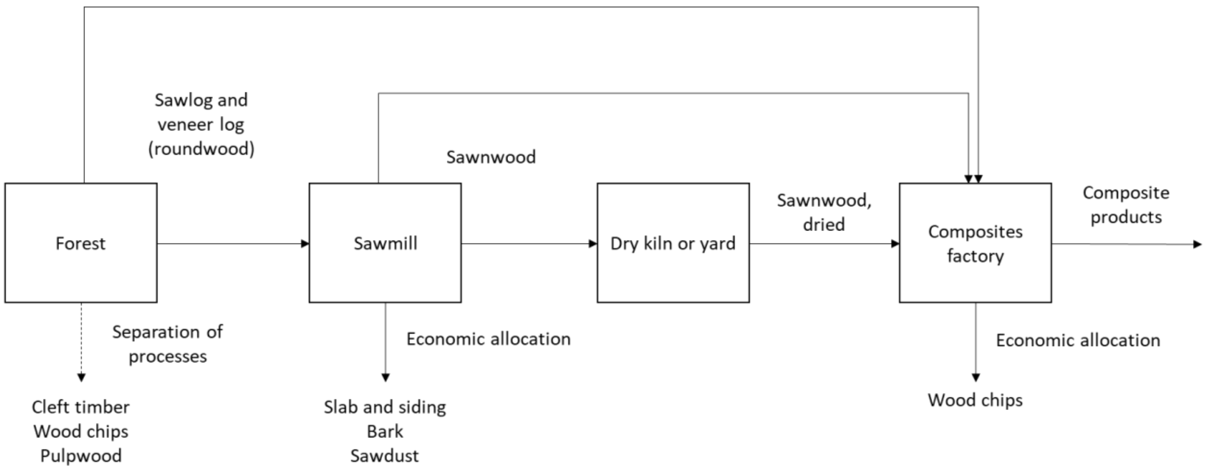


Figure 9.6 Value chain of background processes for laminated timber elements such as CLT & Glulam in Ecoinvent

9.2.2.2 Fibres and particles

Modelling of particle wood products such as hard fibreboard or medium density fibreboard (MDF) is more distinct from solid wood modelling (see also Figure 9.7). Main inputs are formed by pulpwood (roundwood), as well as wood chips, from both forestry and post-consumer wood. In the standard wood modelling of Ecoinvent, secondary wood input is low (examples observed ranging from 3-11%). A small portion of inputs consists of wood industry by-products, such as sawdust and slab and siding.

The models in Ecoinvent for these types of composites include both hardwood and softwood inputs, a distinction from solid wood products where separate models are used.

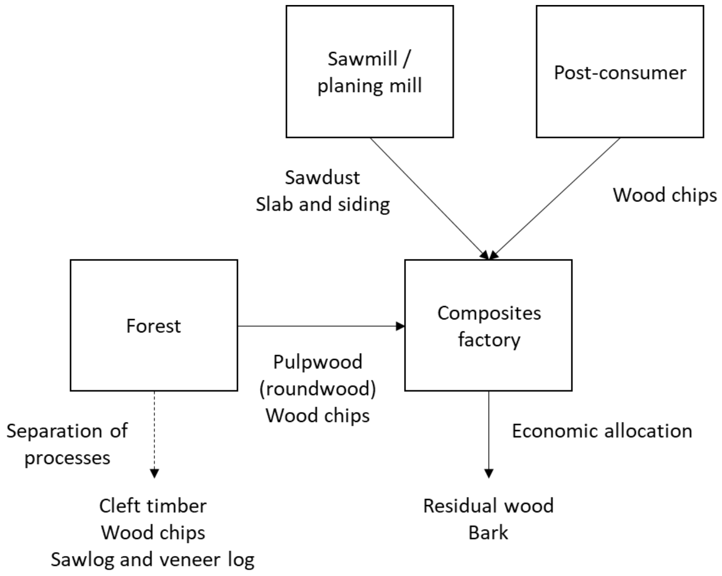


Figure 9.7 Value chain of background processes for particle composites such as hard fibreboard or Medium Density Fibreboard (MDF) in Ecoinvent.

9.2.3 Comparison of conversion efficiencies with reference data

The production steps of wood products from forest (roundwood) to final product include a number of conversions, in which wood volume is lost to different coproducts such as chips and shavings, or shrinkage. An example of the resulting volumetric 'wood balance' applied in Ecoinvent modelling is provided in Figure 9.8.

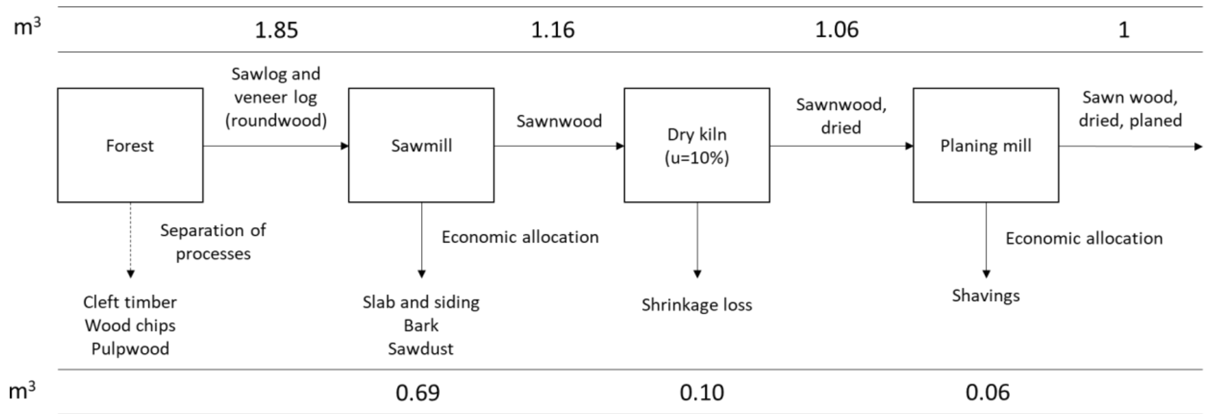


Figure 9.8

Calculated wood balance of the Ecoinvent model sawnwood, beam, softwood, dried (u=10%), planed (Europe without Switzerland)

The accuracy of the conversion efficiencies in Ecoinvent is compared to reference data, for which the report on Forest product conversion factors prepared by the Food and Agriculture Organization of the UN and the International Tropical Timber Organization (144). This report includes conversion efficiencies from roundwood to final product for a number of main wood industry products. It does not list any data on (non-merchantable) forest remains. In Table 9.2, an overview is given of the volumetric wood balance of the four products analysed in Ecoinvent and the reference data. The comparison shows that the resulting wood balance is quite similar to current statistics.

Table 9.2

Comparison of calculated Ecoinvent wood balances of solid beam and board with reference data on solid dried sawnwood products

	Beam, softwood, Ecoinvent	Board, softwood, Ecoinvent	**EU average, softwood**	Beam, hardwood, Ecoinvent	Board, hardwood, Ecoinvent	**EU average, hardwood**
Sawnwood (product)	54,2%	51,8%	**55%**	51,1%	48,9%	**52%**
Chips, slabs and sawdust	37,4%	37,4%	**39%**	40,9%	40,9%	**39%**
Shavings	3,0%	5,3%	**2%**	2,8%	5,0%	**5%**
Shrinkage loss	5,4%	5,4%	**5%**	5,1%	5,1%	**5%**

Source: (3)

The analysis of production efficiencies of laminated timber composites could not be done as accurately, as the forest conversion factors report unfortunately does not include conversions into all composites products, such as CLT and Glulam. When comparing it to the reference data of sawnwood, softwood (Table 9.3), it is suggested by the lower efficiency shown in the Ecoinvent models that production of CLT requires more conversion and creates additional losses (coproducts) in comparison to solid wood products.

Table 9.3

Comparison of calculated Ecoinvent wood balances of CLT with reference data

	CLT, softwood, Ecoinvent	Glulam, softwood, Ecoinvent	**EU average, softwood**
Sawnwood (product)	43,8%	48,0%	**55%**
Chips, slabs and sawdust	49,8%	46,1%	**39%**
Shavings	0,0%	0,0%	**2%**
Shrinkage loss	6,3%	5,9%	**5%**

Source: (144)(147)

For products made out of particles, background models of hard and medium density fibreboard are analysed for wood input and material balance. Appropriate EU statistics are available for these types of products. Product basic density is also listed to get a better idea of comparability (Table 9.4).

When taking into account differences in product density, the conversion efficiency of wood input to product and material balances show similar orders of magnitude.

Table 9.4
Comparison of calculated Ecoinvent wood balances of CLT with reference data

	Fibreboard, hard, Ecoinvent, hard & softwood, wet process	**EU average, Fibreboard, hard, wet process**	Medium density fibreboard, uncoated, Ecoinvent, hard & softwood	**EU average, Fibreboard, medium/high (MDF/HDF)**
Wood input (m^3 solid wood/m^3 product)	2,35	**2,12**	1,51	**1,79**
Product basic density (kg/m^3)	956	**911**	684	**738**
Material balance				
Binders and fillers	3%	**6%**	13%	**9%**
Shavings	5%	**6%**	7%	**6%**
Shrinkage loss	92%	**91%**	80%	**86%**

Source: (144)(147)

9.2.4 Data quality in Ecoinvent

As mentioned before, the main wood value chain modelling already has been included in Ecoinvent version 2. Information in that database typically stems from 1996-2002. To some degree the data is updated, which has been documented in so called 'change reports' that are published with each new release of the database. Without doing extensive study, it is difficult to distinguish what data points have been updated and when they have been updated. For example, the sawmilling dataset is updated in version 3.8 (2021) to a slightly lower ratio of *input roundwood : output sawnwood*, where it is indicated that the time period that this model represents is now 2011-2013 (157). In recent years, some products have been added such as CLT in version 3.7 (146).

9.2.5 Allocation

A number of remarks need to be made on the subject of allocation in Ecoinvent.

The Ecoinvent allocation method 'Allocation, cut-off by classification (unit)' has been the most appropriate database version to use for LCA calculations of construction products. This method complies with the directive of the European standard EN15804 to perform allocation based on economic values (143). The system model "allocation, cut-off by classification", or the cut-off system model, is based on the recycled content, or cut-off, approach. In this system model, wastes are the producer's responsibility (the "polluter pays" principle), and there is an incentive to use recyclable products, because they are available burden free (cut-off), i.e. zero environmental impact (158).

This approaches the requirements of the EN15804 end-of-waste criteria, but does not entirely comply for all product chains. With Ecoinvent version 3.8, an 'allocation EN15804' database version is released where the cut-off point between the primary and secondary system complies with the end-of-waste criteria of the standard EN15804+A2. This means that compared to the cut-off by classification approach, the cut-off point in some supply chains has been adjusted to align with the end-of-waste criteria in EN15804 (147). Whether this has consequences for the product chain of wood or other biobased products (i.e. whether cut-off classification in Ecoinvent for these product database processes matches the EN15804 requirements for end-of-waste criteria) would require further investigation. At the moment of writing this report, the new EN15804 Ecoinvent 3.8 database could not yet be accessed.

Furthermore, as is mentioned above, biogenic carbon resource corrections have been applied in Ecoinvent 3.8, in order to better reflect the physical flows of biogenic carbon from roundwood to final product (147). In earlier versions of the database, biogenic carbon flows are divided based on economic allocation. As a result of higher prices for the main product compared to its coproducts, a higher share of the biogenic carbon content is allocated to the main product, leading to unrealistically high carbon uptake per unit of final product and a lower carbon uptake in coproducts. This might then also lead to higher/lower emissions at the end of life The effect of applying this correction is investigated in section 9.2.6.

Lastly, the economic data from which the allocation shares are derived appears to be quite outdated. In a number of cases, methodology provided by Ecoinvent suggests that (by)product price data is used of reference years as far back as 2004 (159). As an example, in Table 9.5 and 9.6, an overview is given of the resulting allocation of impacts from the sawmilling and planing processes of softwood (beam) in Ecoinvent 3.8. The common picture is that the vast majority of impacts is allocated to the main product of both processes (sawnwood).

The low amount of environmental impacts allocated to the by-products means that for products that are (partly) produced out of these by-products, such as particle or fibre board, a relatively low environmental impact is calculated. As environmental impact analysis of wood products is becoming increasingly important, it is increasingly important to have accurate economic allocation parameters. In this research, no analysis has been done on the accuracy of the current economic allocation factors. Such an analysis is complicated by the fact that there is currently high price volatility in the wood markets.

Table 9.5 Allocation of impacts in sawmilling process of softwood (Cut-off, U, Ecoinvent 3.8)

	% of allocated impacts
Sawnwood, softwood, raw	91,5%
Slab and siding, softwood, wet, measured as dry mass	5,4%
Bark	1,7%
Sawdust, loose, wet, measured as dry mass	1,5%

Table 9.6 Allocation of impacts in planing process of beam, softwood (Cut-off, U, Ecoinvent 3.8)

	% of allocated impacts
Sawnwood, beam, softwood, dried (u=10%), planed	98,1%
Shavings, softwood, loose, measured as dry mass	1,9%

9.2.6 Interpretation and sensitivity analysis of biobased products in the Ecoinvent database

In this section, further interpretation and analysis of issues found in the Ecoinvent background databases is provided. The analyses in this chapter are based on data from the Ecoinvent database versions 3.7.1 and 3.8, characterized results are created with the following method: "EN 15804 + A2 Method V1.02 / EF 3.0 normalization and weighting set".

9.2.6.1 Effect of carbon resource corrections

A comparison between calculated results from Ecoinvent 3.7.1 and 3.8 has been made to gain insights on the topic of resource corrections for uptake of biogenic carbon. In Table 9.7 the results are shown for CLT and (solid) wood product beam. Both product are made out of European softwood. It should be noted that part of the difference between the results of Ecoinvent version 3.7.1 and 3.8 is caused by an update of the sawmilling efficiency in version 3.8. The calculation shows that the impact of carbon resource corrections is significant as the net amount of carbon uptake is decreased by up to 50%.

Table 9.7 Comparison on the biogenic CO_2 in Ecoinvent 3.7.1 - 3.8, characterized LCA-results with the standard EN15804+A2 method.

	EI 3.7.1	EI 3.8
1 m3 cross-laminated timber {RER}| cross-laminated timber production - Climate change – Biogenic - kg CO2 eq	-1497,2	-696,1
1 m3 sawnwood, beam, softwood, dried (u=10%), planed {Europe without Switzerland} - Climate change – Biogenic - kg CO2 eq	-1299,9	-761,0

9.2.6.2 Contributions of CO_2-flows in wood product value chain

In order to put the impact of biogenic carbon for biobased products into context, it is relevant to assess the proportion of biogenic carbon in relation to other (fossil) carbon flows, including energy use for harvesting and processing. In Figure 9.9, the main carbon flows are depicted:

- Biogenic CO_2 uptake: uptake of CO_2 by trees through the process of photosynthesis;
- Emissions from burning fossil fuels: carbon emissions due to energy use in various types of machinery used in the wood product value chain, mostly through diesel consumption;
- Emissions related to Land Use and Land Use Change: carbon emissions due to changes in land use, for example due to transformation of forest into roads required for forestry;
- Indirect emissions: carbon emissions related to production of energy carriers (e.g. electricity, or refining of oil), transportation (e.g. from forest to sawmill) and emissions related to production of capital goods (e.g. forestry machinery, buildings, trucks);
- End of life: After possible reuse or recycling of a wood product, it is eventually disposed of creating biogenic carbon emissions through incineration or landfilling.

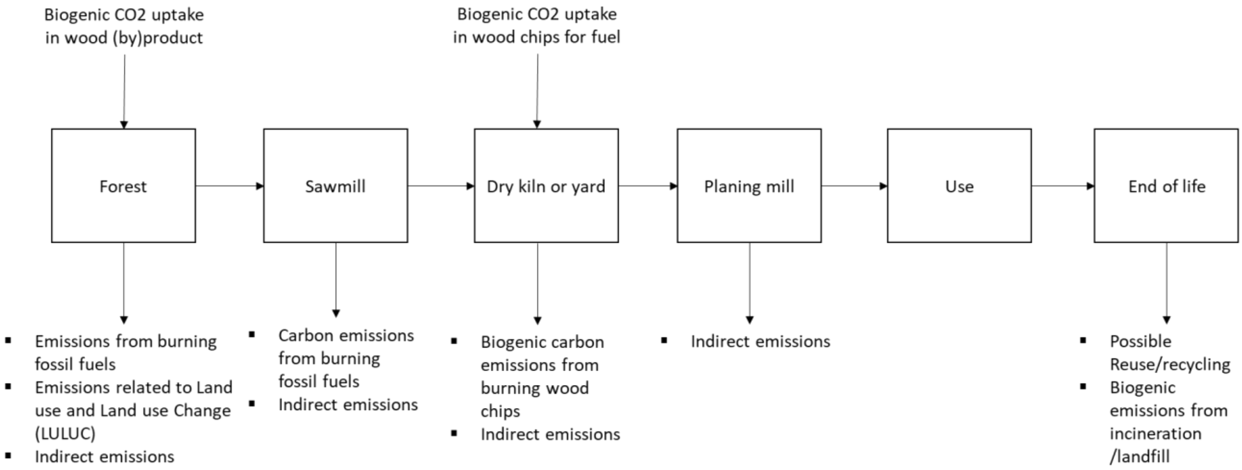
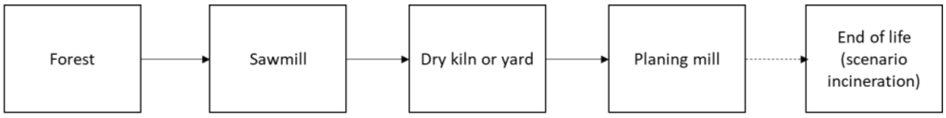


Figure 9.9 Overview of carbon in- and output in the wood product life cycle

In Table 9.8, the characterized GWP (CO_2-equivalent) results of fossil and biogenic carbon are shown for the Ecoinvent process of *Sawnwood, beam, softwood, dried (u=10%), planed {Europe without Switzerland}| market for sawnwood, beam, softwood, dried (u=10%), planed | Cut-off, U*. Calculation is done following the methods prescribed by standard EN15804+A2. For the end of life of the wood product, a scenario is depicted in which the product is 100% incinerated, releasing the embedded carbon (uptake by the forest) into the air again. Calculation of emissions is done with Ecoinvent 3.8, so including carbon resource corrections.

The results show that the main part of the total carbon flows is biogenic in origin, related to carbon uptake and end of life incineration. Additionally, incineration of wood chips for drying creates biogenic carbon flows, for which the carbon uptake (with sustainable forest management) and emissions are balanced if carbon resource corrections are correctly included.

Emissions due to fossil fuels are relatively low compared to the biogenic carbon flows.
However, when looking at the net emissions, fossil CO_2-emissions are the most relevant contributor to climate change, as emissions due to incineration negate the effects of carbon uptake.



	Forest	Sawmill	Dry kiln or yard	Planing mill	End of life (scenario incineration)
Climate change – Fossil	29,6	13,4	13,5	7,6	
Climate change – Biogenic	-787,3	0,4	5,01	-0,2	782,1
Climate change – Land use and LU change	0,9	0,02	0,1	0,01	
Total	**-756,7**	**13,8**	**18,6**	**7,4**	**787,3**

Figure 9.10
Overview of characterized results for Climate Change (kg CO_2-equivalent) of the value chain of *Sawnwood, beam, softwood, dried (u=10%), planed {Europe without Switzerland}| Cut-off, U*, with the end of life scenario in which the wood is incinerated.

The largest fossil CO_2-emissions occur in forestry, of which underlying contributions are investigated more thoroughly. For softwood, pine, from Germany, the contribution of different processes to the various climate change indicators is provided in Table 9.8, including impact of (EU) average transport to a sawmill. Results show that the average (EU) transport to the sawmill has a relatively high contribution to total fossil carbon emissions (33%), next to power sawing (17%) and skidding (18%).

Table 9.8 Overview of characterized results for Climate Change (kg CO_2-equivalent) of *1 m3 Sawlog and veneer log, softwood, measured as solid wood under bark {DE}| softwood forestry, pine, sustainable forest management | Cut-off, U*, with the addition of transport taken from the EU region market background model of softwood. Calculation of characterized LCA-results with the standard EN15804+A2 method.

Effect category	**Climate change - Fossil**	**Climate change - Biogenic**	**Climate change - Land use and LU change (LULUC)**	**Climate change (total)**
Unit	*kg CO2 eq*	*kg CO2 eq*	*kg CO2 eq*	*kg CO2 eq*
Carbon uptake (Carbon dioxide, in air)	0,0	-887,6	0,0	-887,6
Forwarding	1,2	0,002	0,0002	1,2
Gravel, crushed	1,6	0,02	0,002	1,6

Harvesting, forestry harvester	1,1	0,03	0,02	1,1
Power sawing	3,4	0,91	0,87	5,2
Skidding	3,6	0,01	0,001	3,6
Tree seedling, for planting	0,5	0,02	0,001	0,5
Diesel, burned in building machine	1,8	0,001	0,0001	1,8
Transport, freight, lorry, unspecified	6,5	0,02	0,002	6,5
Total	**19,6**	**-886,6**	**0,9**	**-866,1**

Lastly, the contribution of adhesives in composite products is investigated by taking a closer look at the contribution within the production of Cross-Laminated Timber (CLT), shown in Table 9.10. Results show that the contribution of adhesives to fossil carbon emissions in the standard Ecoinvent model is approximately 20%.

Table 9.9 Overview of characterized results for Climate Change (kg CO_2-equivalent) of *cross-laminated timber {RER}| cross-laminated timber production | Cut-off, U.* Calculation of characterized LCA-results with the standard EN15804+A2 method.

Effect category	Unit	Total	Melamine urea formaldehyde adhesive	Polyurethane adhesive	Others contributions
Climate change - Fossil	kg CO2 eq	141,9	10,3	18,8	112,8
Climate change - Biogenic	kg CO2 eq	-696,1	-0,019	0,24	-696,3
Climate change - Land use and LU change	kg CO2 eq	1,2	0,0055	0,014	1,18
Climate change (total)	**kg CO2 eq**	**-551,9**	**10,3**	**19,0**	**-581,2**

9.2.6.3 GHG emissions of non-sustainably sourced wood products

As described in section 9.2.1, all forestry background modelling in Ecoinvent is characterized as sustainable forest management, implying carbon neutrality. If a wood product is not sustainably sourced (forest degradation), biogenic carbon emissions would not be compensated for by uptake of newly grown forest. This cannot be calculated using Ecoinvent modelling but is estimated manually.

First of all, deforestation would create net greenhouse gas emissions at the end of life of the product. This is recognized by the EN 16485 'Round and sawn timber - Environmental Product Declarations - Product Category Rules for wood and wood-based products for use in construction', in which rules for carbon neutrality are specified (see also section 9.4.2.2). If carbon neutrality cannot be assumed or proven, then this standard imposes the contribution of biogenic CO_2 to the GWP to be > 0 over the lifecycle, to consider forest degradation.

To represent and compare this stipulation of the EN 16485, the LCA calculation of CO_2 uptake (carbon storage) is manually corrected to 0. Table 9.10 shows the estimated impact of this correction for CLT, derived from Ecoinvent 3.8.

This comparative calculation shows that the sensitivity on this issue is very high. Although having a net carbon uptake of zero is not expected to be a realistic scenario, this particular standard imposes it when carbon neutrality of the forest system cannot be assumed or proven. Therefore, this aspect in LCA modelling needs specific attention in justification of the sourcing.

Furthermore, there is an impact of greenhouse gas emissions of the non-merchantable parts of harvested wood. This includes tree tops, branches, twigs, foliage, stumps and below-ground components (roots). The ratio of non-merchantable wood to merchantable wood differs greatly on the type of tree and with stand age. The IPCC has created an overview of default biomass conversion and expansion factors (BCEF), specifically the BCEF for conversion of wood and fuelwood removal volume to above-ground biomass removal ($BCEF_r$), which is 0.55 – 1.33 ton/m^3 of wood volume for pine and spruce (depending on growing stock level, the volume of all living trees in a given area of forest or wooded land that have more than a certain diameter at breast height). If the growing stock level is high, the $BCEF_r$ is lowest, meaning that a high proportion of the biomass is merchantable. Additionally, standard ratios of below-ground biomass to above-ground biomass are provided by the IPCC, which is 0.20-0.40 for conifers. All factors are based on dry wood mass (160).

Without more specific data, it is difficult to estimate what the potential GHG emissions of non-merchantable biomass is for a specific product like CLT. However, based on assessment of these factors it can be estimated that this is at least in the order of 0.3 as a ratio to the merchantable biomass. This ratio is the addition of 0.2 for below-ground biomass and 0.1 for above-ground biomass at a high growing stock level (>100 m^3).

Table 9.10 Estimation of the impact of non-sustainably managed forest on CLT production (A1-A3). Calculated using Ecoinvent 3.8, characterization factors as in EN15804+A2 standard. Non-merchantable biomass factor based on IPCC report.

	Sustainably managed forest (carbon neutral)	Non-sustainably managed forest, emissions of merchantable part	Non-sustainably managed forest, emissions of non-merchantable part
1 m3 cross-laminated timber {RER}| cross-laminated timber production - Climate change – kg CO_2 eq (total)	- 551,9	143,1	165,6

9.2.7 Conclusions on Ecoinvent

The main conclusions of the database analysis of Ecoinvent are as follows.

The first observation made is that within the modelling of forestry processes, 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 on this point. The definition of sustainable forest management that can be found indicates that sustainable forest management as defined by Ecoinvent does not include the principle of carbon neutrality. The modelling should therefore either reflect the average emissions from non-merchantable wood that remains in the forest, or there should be a distinction into different types of background models that reflect both carbon neutral and non-carbon neutral forestry. As will be shown later in the EPD-analysis, the current modelling approach does comply with the PCRs of wood products.

Furthermore, biogenic carbon resource corrections have been applied in Ecoinvent 3.8, in order to better reflect the physical flows of biogenic carbon from roundwood to final product. In earlier versions of the database, biogenic carbon flows are divided based on economic allocation. As a result of higher prices for the main product compared to its coproducts, a higher share of the biogenic carbon content is allocated to the main product, leading to unrealistically high carbon uptake per unit of final product and a lower carbon uptake in coproducts. This might be observed in existing EPDs in which biogenic carbon is declared and included in the results (EN 15804+A2). Biogenic carbon balances should be carefully modelled and possibly adjusted to compensate, especially for wood products. If the way in which the GWP-indicators are calculated and/or weighted in EN 15804 should change in the future, this will be an even more important consideration. As the earlier versions (3.7 and previous) of Ecoinvent might still be used for a while, careful calculation of biogenic carbon should be applied when creating EPDs.

Lastly, the comparisons of conversion efficiencies of selected wood products (conversion of roundwood to solid and composite products, both soft and hard wood) to reference data show that the Ecoinvent modelling seems to reflect current statistics accurately. However, the economic data from which the allocation shares are derived is outdated, possibly leading to an inaccurate reflection of environmental impacts. As environmental impact analysis of wood products is becoming increasingly important, it is imperative to regularly update such allocation parameters.

9.3 Gabi database analysis

In addition to the Ecoinvent database, the Gabi database is used worldwide for conducting LCA of construction products. The analysis of the Gabi background database in this research is less extensive than the analysis of the Ecoinvent database, e.g. conversion efficiencies from solid wood (roundwood) to product have not been performed for this database.

In the following sections, the modelling steps are discussed in terms of accurate representation, methodology and data quality, particularly pertaining to biogenic CO_2. Significant omissions were not identified.

9.3.1 Solid wood product modelling

In comparison with the Ecoinvent database, the Gabi database has a more condensed type of modelling for its standard models of wood products. The modelling steps are not split up into separate models that represent the processes of forestry, sawing and drying. Instead, a single model usually includes multiple steps of the value chain, for example from forestry to sawn wood, dried and packed. Part of the models are specifically tailored to construction product EPDs and mention explicitly a 'cradle-to-gate' scope, in compliance with EN15804 modules A1, A2 and A3. This makes it harder to for an LCA practitioner to adjust the modelling in or to reflect an actual manufacturer's situation, as it is more difficult to alter individual production steps and inputs within those production steps.

An example of the Gabi modelling is given in Figure 9.11, for the process data set *Timber spruce (12% moisture; 10.7% H2O content) (EN15804 A1-A3); technology mix; production mix, at plant; 12% moisture / 10.7% water content (en)*. The modelling includes creation of by-products such as bark, wood chips and sawdust, similar to Ecoinvent modelling. The wood is debarked, cut, sorted, oven dried and finally packed (161).

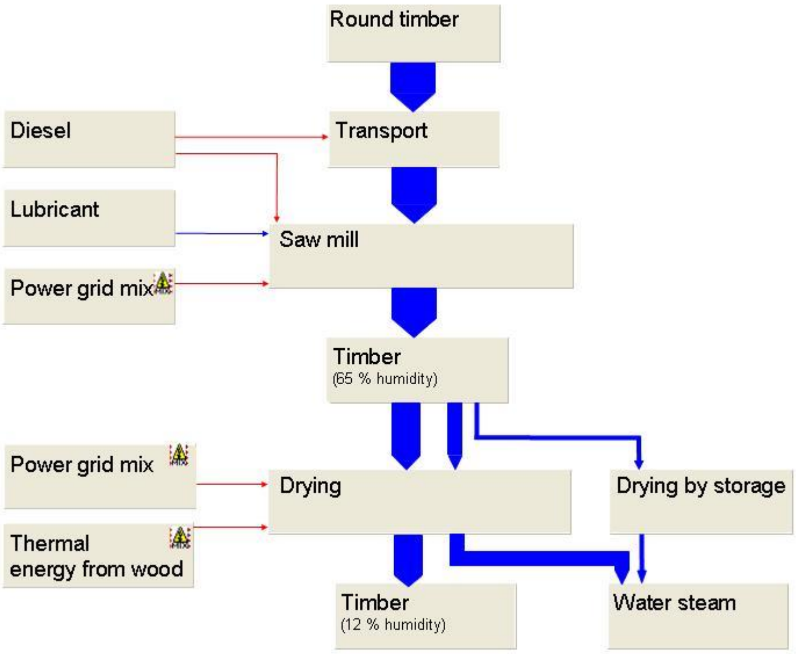


Figure 9.11
Schematic overview of process data set: Timber spruce (12% moisture; 10.7% H2O content) (EN15804 A1-A3); technology mix; production mix, at plant; 12% moisture / 10.7% water content) (161).

9.3.2 Composite wood product modelling

The standard Gabi database does not feature the large range of composite wood products that are found in Ecoinvent. The models that are included show similar production steps. An example of the Gabi modelling for laminated wood products is given in Figure 9.12, for the process data set *Laminated woodboard softwood (EN15804 A1-A3); technology mix; production mix, at plant; 515 kg/m3 density at 12% moisture (en)*. The modelling includes the abovementioned cradle-to-gate scope and includes creation of a number of by-products (162).

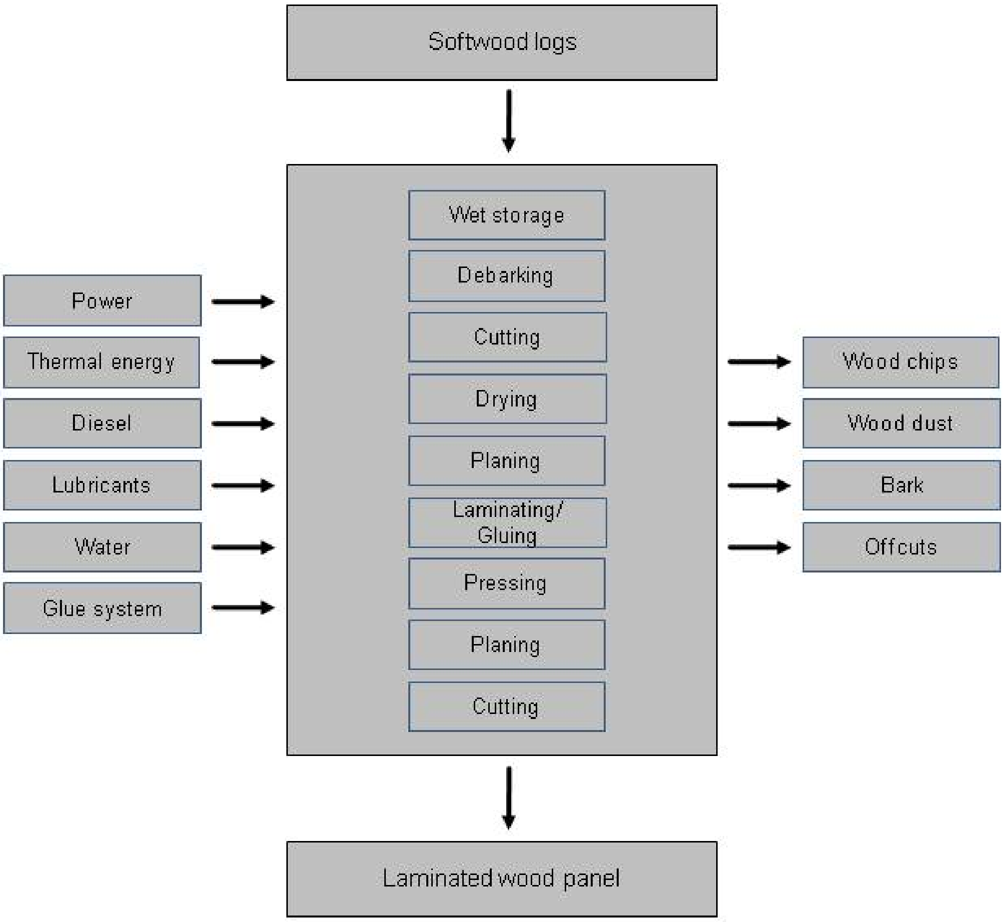


Figure 9.12
Schematic overview of process data set: Laminated woodboard softwood (EN15804 A1-A3); technology mix; production mix, at plant; 515 kg/m3 density at 12% moisture (en) (162).

Similarly to laminated products, the Gabi database has a limited choice of composite wood products made out of particles or fibres. The models that are included show similar production steps in comparison to Ecoinvent, include usage of (pre- and post-consumer) residue wood.

An example is given in Figure 9.13, for the process data set *Particle board; P5 (V100); production mix, at plant; 7,8% water content (en)*. This modelling does not include a cradle-to-gate scope/EN15804 specification (163).

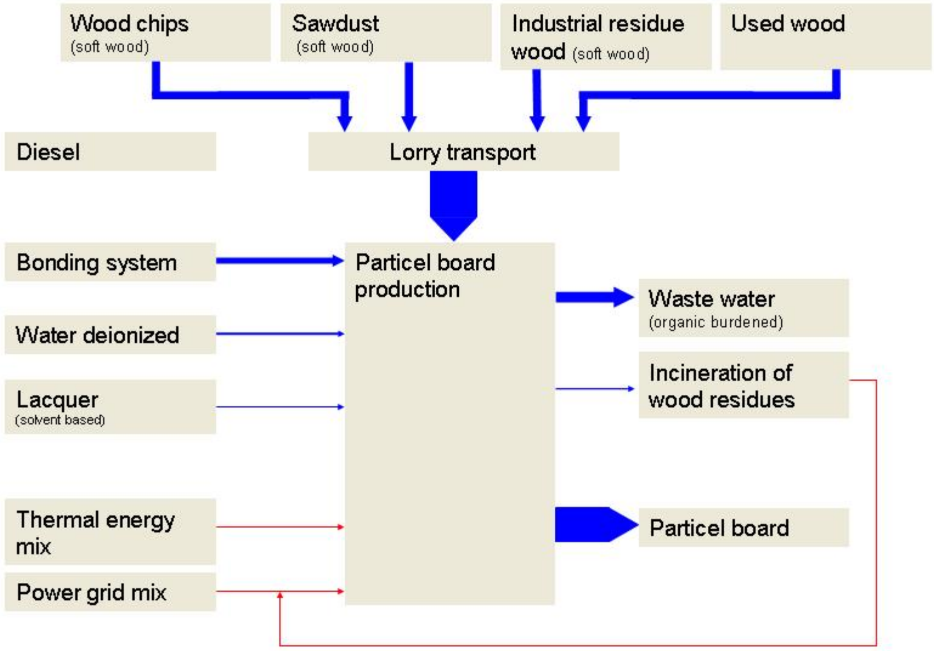


Figure 9.13
Schematic overview of process data set: Particle board; P5 (V100); production mix, at plant; 7,8% water content (163).

9.3.3 Sustainable forest management and carbon storage

In the Gabi documentation, the term 'sustainable forest management' is not explicitly used in contrast to the Ecoinvent database. However, some datasets mention that CO_2 uptake in the forest is included. Background documentation of agricultural modelling does not mention explicitly that carbon neutrality is applied, however it states that biogenic CO_2 sequestered in plants and further products is accounted for in the inventory. Additionally, (direct) land use change is considered (164). There is no mention of emissions from non-merchantable wood that remains in the forest, including above-ground components (tree tops, branches, twigs, foliage, sometimes stumps) and below-ground components (roots). In some datasets, the process of planting of new tree seedlings and transformation from and to forest area was explicitly taken into account.

This implies that similar assumptions are used in comparison to Ecoinvent's approach on sustainable forest management and carbon neutrality. This is confirmed by the EPD assessment of EPDs created with Gabi, which indicate 100% uptake of biogenic CO_2 in module A1 within the product and no biogenic emissions.

Furthermore, all modelling documentation observed includes the following remarks:

- Credits associated with temporary carbon storage or delayed emissions are not considered in the calculation of the Global Warming Potential impacts for the default impact categories;
- Biogenic uptake and emissions are modelled separately;

- For land use change, all carbon emissions and uptakes are inventoried separately for each of the elementary flows.
- Soil carbon accumulation (uptake) via improved agricultural management is excluded from the model (163)

In conclusion, the observations of Gabi suggest similar approaches as used in Ecoinvent on the subject of Sustainable forest management and carbon storage.

9.3.4 Allocation

Allocation in the wood product modelling of Gabi is done based on economic values. It is recognized that this might result in distorted biogenic carbon balances, as this should be allocated based on physical properties. The Gabi database uses a similar approach to Ecoinvent in order to provide accurate tracking of biogenic carbon, applying similar resource corrections in all models that include biomass, including for example wood fibre in a cardboard box, from a cradle-to-gate perspective. It does not cover products where atmospheric carbon is removed during its use, for example through carbonation of concrete.

The Gabi software includes tooling to accurately track biogenic carbon through the life cycle of a product. Here, the user can specify the carbon content of a final product, which is then used to accurately calculate carbon uptake from biomass and (possible) releases during the end-of-life stage (165).

9.3.5 Conclusions on the Gabi database analysis

The main conclusions of the database analysis of Gabi are as follows.

Firstly it is observed that Gabi has a similar approach to carbon neutrality within wood product modelling as Ecoinvent. However, hardwood and softwood forestry processes are not explicitly characterized as ‘sustainable forest management’. In some datasets, the process of planting of new tree seedlings and transformation from and to forest area was explicitly taken into account, indicating a very similar approach to modelling of (sustainable) forest management.

Furthermore, biogenic carbon resource corrections have been applied also in the Gabi background database, in order to better reflect the physical flows of biogenic carbon from roundwood to final product. Biogenic carbon balances should be carefully modelled and possibly adjusted, especially for wood construction products that consist mostly of biomass. Gabi software offers specific tooling for this.

9.4 EPD assessments

9.4.1 Introduction

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 sections provides an assessment of these different standards and product category rules (PCR) and its impact on selected EPDs of wood based products. The assessment is based on analysing 48 EPDs from 6 different EPD programs.

9.4.2 PCR assessment for wood based products

This section offers an overview of the applicable PCR (product category rules) for EPDs on wood based products. The PCR rules have been analysed on their specific rules for carbon dioxide and biogenic carbon flows.

9.4.2.1 Standard EN 15804

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.

EN15804+A2 has several specific category rules for products that contain biogenic carbon. All products that contain biogenic carbon must be modelled on their full life cycle, i.e. cradle to gate EPDs are not allowed. Furthermore, EN15804+A2 states that the effect of temporary and permanent carbon storage and delayed emissions shall not be included when calculating the greenhouse warming potential (GWP). Furthermore, biogenic carbon in landfills must be modelled without time limit.

According to EN15804+A2, removals of biogenic carbon dioxide in biomass should be characterised in the LCA as '-1 kg CO_2eq.' when entering the product system and as '+1 kg CO_2eq.' for its emission and when transferred into subsequent product systems. This means that biogenic CO_2 is considered captured when the product is in usage and that the same amount of biogenic carbon is released at the end of the material's life (incineration or landfill). The EN15804+A2 excludes biomass from native forests in this carbon neutrality method. Native forests do not include short term forests, degraded forests, managed forests and forests with short-term or long-term rotations. For native forests all related CO_2 emissions should be considered under global warming potential of land use and land use change (GWP-LULUC). This includes soil emissions and products derived from native forests. The CO_2 uptake from biomass from native forests is considered '0' (i.e. steady-state).

9.4.2.2 Standard EN 16485

The EN 16485 “Round and sawn timber - Environmental Product Declarations - Product category rules for wood and wood-based products for use in construction” further specifies the rules for carbon neutrality. The EN 16485 only 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 the contribution of biogenic CO_2 to the GWP to be > 0 over the lifecycle, as to consider forest degradation.

EN 16485 states: ‘Effects on forest carbon pools related to the extraction of slash, litter or roots are not attributable to the material use of wood and are therefore not considered in this document’. This means that no environmental impact is attributed to the biogenic material that remains in the forests after felling.

9.4.2.3 Standard EN 16449: 2014

The EN 16449 “Wood and wood-based products - Calculation of the biogenic carbon content of wood and conversion to carbon dioxide” provides a calculation method for quantifying the carbon capture and storage for wood and wood based products. The standard aims to be used in the work for EN 15804 and as a method for calculating this information in PCR (EN 16485 named specifically) and EPDs.

The standard provides a simplified calculation for CO_2 based on carbon content (atomic weight of carbon vs atomic weight of carbon dioxide) in a product, corrected for density and moisture content. The standard provides a calculation example for laminated timber;

Formula (1), Calculation example

Consider 25 m^3 of European whitewood incorporated into a building as glulam or cross-laminated timber – from EN 350-2 the density value of European whitewood at 12 % moisture content is 460 kg/m^3. Using Formula (1), atmospheric carbon dioxide based on biogenic carbon content of, say, 95 % of the total volume by way of allowance for the glue content, amounts to 17 883 kg.

$$P_{CO_2} = \frac{44}{12} \times 0,5 \times \frac{460 \times 25 \times 0,95}{1 + \frac{12}{100}} = 17\,883 \text{ kg } CO_2 \qquad \text{(A.1)}$$

In any situation, if the precise moisture content of the wood and wood products is uncertain, a higher moisture content for a given volume of wood will provide a more conservative estimation of carbon dioxide.

For any project, estimation of the total amount of carbon dioxide is determined by quantifying the volume of wood of each species used in each wood and wood-based product in each application and applying the above calculation in each case, (i.e. $P1co_2 + P2co_2$, etc.).

Based on the life cycle inventory information in Ecoinvent 3.7 of 1 m^3 cross-laminated timber, region Europe, a comparative calculation was made on biogenic CO_2 content with this standard and the Ecoinvent background profiles. The comparative calculations was done to identify whether there are large differences among differently applied standards.

The results on biogenic CO_2 balance are shown below.

- Biogenic CO_2 emission based on EN 16449:2014 = - 618 kg/m^3

The EN 15804+A2 (2019) is of a later date and calculates the biogenic CO_2 *equivalents*, also taking carbon monoxide and methane into account. However, EN 15804+A2 also notes that the biogenic carbon content of wood can be calculated according to EN 16449. The EN 16485 only prescribes the use of EN 16449 for calculating the carbon storage that shall be documented as technical scenario information in CO_2-eq). It should be considered that the results from EN 16449 are in biogenic carbon content and carbon dioxide emissions only, not CO_2 equivalents.

The results on biogenic CO_2 balance are then as follows:

- Biogenic CO_2 emission based on EN 15804+A2 = - 1672 kg/m^3 (without resource correction)
- Biogenic CO_2 eq. emission based on EN 15804+A2 = - 1497 kg/m^3 (without resource correction)
- Biogenic CO_2 emission based on EN 15804+A2 = - 835 kg/m^3 (with resource correction based on mass balance in Ecoinvent 3.8). This is currently the required method.

It goes to show that depending on the standard applied, this results in a range of biogenic carbon values whether expressed as biogenic CO_2 or biogenic CO_2 equivalents. Without the proper context, erroneous reporting of biogenic carbon values are then easily made.
Although there are some uncertainties in the comparison, regarding the resource correction used, it is clear that this is a complex aspect of the LCIA for wood products that should be transparent on calculation methods and used data. Currently, this is not the case, making it harder to make accurate comparisons.

There are doubts on our side on the current practical use of this standard after the introduction of the EN 15804+A2. In the EPD search, 2 EPDs refer to this standard, concerning EN 15804+A1 EPDs. However, it shows that potentially very large differences in biogenic CO_2 emission occur in EPDs of construction products when applying different standards and/or PCR. Therefore, it demonstrates a potentially large inconsistency when it comes to comparing EPDs.

9.4.2.4 Standard ISO 14067:2018

This a general standard on 'Greenhouse gases – Carbon footprint of products -Requirements and guidelines for quantification'. This standard specifies requirements, principles and guidelines for quantifying and reporting the carbon footprint of a product. This standard only considers the single impact category 'climate change'. The ISO 14067:2018 will be compared to the EN 15804+A2 and EN 16485. This comparison will be added in a next version of this report.

9.4.2.5 Platform specific category rules

Different EPD platforms provide specific PCR on wood based products. These specific PCR, except the rules in France, are in line with EN 15804+A2 and EN 16485 regarding biogenic carbon.

FDES

In France the EPDs, or FDES (fiche de déclaration environnementale et sanitaire) are based on 'NF EN15804+A1' and 'NF EN 15804/CN'. These standards describe the applicable product category rules (RCP, règles de categories de produits). These standards are based on EN15804+A1, which means that set A2 does not need to be included in French EPDs and that the biogenic carbon flow is not visible per life cycle stage. The French EPDs do show the total biogenic carbon storage (CO_2-eq) and the biogenic materials masses (kg). These indicators are shown per functional unit and calculated according to NF EN 16485. In France the NF EN 15804+A2/CN will eventually replace the A1 version. No formal regulation information has been found on the transitioning period.

IBU

IBU specifies in their PCR for "Solid wood products" that for the indicator 'use of renewable secondary fuels' the lower caloric value of absolutely dry wood should be applied. This is relevant as the EPDs do show the moisture percentage in the mass-balance. In line with EN 15804, several platform specific category rules mention that the carbon flow to and from bio-based materials must be accounted as CO_2 in the life cycle module where the impact occurs.

Norway

The Norwegian PCR Part B for wood and wood-based products specifies that biogenic carbon must be separated in global warming potential from 'instantaneous oxidation of biogenic carbon', 'biogenic carbon in products' and in the sum of both indicators 'global warming potential'.
The instantaneous oxidation category shows the biogenic carbon content accounting for all emissions at harvest.
The biogenic carbon in products category shows the carbon flows in the life cycle module where the impact occurs. This follows the harvested wood products methodology in IPCC.

Environdec and EPD Italy

The wood-based PCR rules from Environdec and EPD Italy follow EN15804+A2 and EN16485. The PCR for construction products from Environdec prescribes the reporting of the additional indicator: GWP-GHG (Global warming potential, greenhouse gas). This indicator includes the greenhouse gases that are included in GWP-total (as defined in EN15804+A2), excluding biogenic carbon dioxide. The GWP-GHG factor is comparable to the GWP indicator as defined in EN15804:2012+A1. This factor is added for comparability between EPDs that use the A2 indicators set and the A1 indicators set.

The analysed platform specific PCR rules are shown in Table 9.11.

Table 9.11 Analysed platform specific PCR

Platform	PCR
IBU	Part A
IBU	Part B Requirements on the EPD for www.ibuepd.com Solid wood products
IBU	Patio coverings made from wood polymer composites (WPC)
IBU	Prefabricated wood-based load bearing stressed skin panels
IBU	Solid wood products
IBU	Wood based panels
IBU	Wood cement - Mineral-bonded wooden composites
MRPI	Dutch "bepalingsmethode milieuprestatie bouwwerken"
EPD-norge	NPCR 015 Wood and wood-based products for use in construction August 2013 17
EPD-norge	NPCR 015 2019 Part B for Wood and Wood-Based Products final version.pdf
EPD-norge	NPCR 015 2021 Part B for Wood and Wood-Based Products (A2-2019 edit) v4 071021 (1).pdf
Inies, FDES	EN15804+A1, NF EN 15804/CN
EPD Italy	PRODOTTI E SERVIZI PER LE COSTRUZIONI
EPD Italy	CONSTRUCTION PRODUCTS AND CONSTRUCTION SERVICES - WOOD AND WOOD-BASED PRODUCTS FOR USE IN CONSTRUCTION
Environdec	BASIC PRODUCTS FROM FORESTRY PRODUCT CATEGORY CLASSIFICATION: UN CPC 031. PCR 2020:05 VERSION 1.0. Based on EN 16760, EN 14067
Environdec	WOOD AND WOOD-BASED PRODUCTS FOR USE IN CONSTRUCTION (EN 16485:2014), complimentary to PCR 2019:14 Construction products, version 1.0
Environdec	CONSTRUCTION PRODUCTS, PCR 2019:14 VERSION 1.11

9.4.2.6 Comparison of GWP characterisation factors between EN15804+A1 and EN 15804+A2

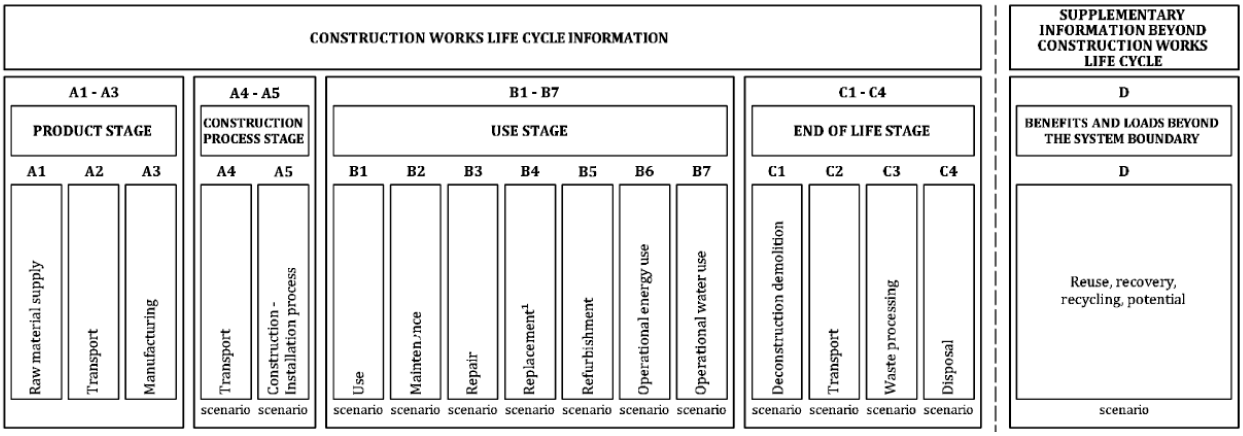
The characterisation factors for GWP have changed from EN15804+A1 and EN15804+A2. This will lead to different results, that can be in the order of 10-15%. Some of the main characterisation factors from EN 15804+A1, EN 15804+A2 and EF 3.0 (PEF) are shown in Table 9.12.

Table 9.12 Characterisation factors

	EN 15804+A1	EN 15804+A2 according to IPCC 2013		EF 3.0 (PEF)	
	GWP	GWP-fossil	GWP-biogenic	GWP-fossil	GWP-biogenic
CO_2	1	1	0	1	0
CO_2 biogenic	0	0	1	0	0
CH_4 fossil	30	36.75	0	36.8	0
CH_4 biogenic	28	0	36.75	0	34
N_20	265	298	0	298	0

9.4.3 Assessment of EPDs for wood products

The purpose of and 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:



An initial analysis of 48 EPDs on wood products was performed (see Annex II for an overview). This selection contained EPDs from IBU, MRPI, Eco-platform, EPD Norway DIGI, Environdec, Ienies and EPD Italy. From this collection, eleven EPDs were selected for further elaboration. The selection was made in such a way that it represents the different methodologies and products (see Tabel 9.13).

Table 9.13 Overview of the analysed EPDs

Platform	Product type	Product	Declared modules	Year	Reference service life (years)	EPD owner	Main standard
IBU	Wood based panels	Medium Density Fibreboards EGGER MDF / Mitteldichte Faserplatten	A1-A3, C1-C4 ,D	2021	10-40	Egger	EN 15804+A2
IBU	Structural timber products	Glued laminated timber, glued solid timber, block glued glulam, special components / Brettschichtholz, Balkenschichtholz	A1-A3, C1-C4, D	2021	>100	HASSLACHER Holding GmbH	EN 15804+A2
IBU	Structural timber products	HASSLACHER CROSS LAMINATED TIMBER/ Brettsperrholz HASSLACHER CROSS LAMINATED TIMBER	A1-A3, C1-C4 ,D	2021	>100	HASSLACHER Holding GmbH	EN 15804+A2
MRPI	Wood based panels	Hakwood Duoplank® in European Oak or European Ash in 15mm (5/8”) and 20mm (3/4”)	A1-A3,A4,A5, B2, B3,C2,C4,D	2019	50	Hakwood	EN15804
IBU	wood fibre insulation boards	Holzfaserdämmplatten	A1-A3, A5, C3, D	2020	40	GUTEX Holzfaser-plattenwerk	EN 15804
Eco-platform / EPD-Norway DIGI	Wood based panels	Brannpanel Natur - Brannimpregnert Thermowood av furu	A1-A3 ,A4 ,A5, B2, B3, C1, C2, C3, C4, D	2019	60	Woodify AS	EN 15804+A1
Environdec	Planed wood products	Swedish sawn and planed wood product	A1-A3, C1-C4, D	2021	-	Swedish Wood	EN 15804+A2
Environdec	Wooden panels and floors	ThermoWood	A1-A3, C1-C4, D	2021	> 100	Skora Enso	EN 15804+A2

Platform	Product type	Product	Declared modules	Year	Reference service life (years)	EPD owner	Main standard
FDES, Inies	Structural timber products	Mur ossature bois en bois de france	A1-A5, B, C1-C4, D	2021	100	Fédération Nationale du Bois	NF EN 15804+A1
FDES, Inies	Oriented strand board	Panneaux de lamelles de bois minces orientées OSB (oriented strand board) de type 3 (panneaux travaillants utilisés en milieu humide) bruts	A1-A5, C1-C4, D	2019	100	Institut technologique FCBA	NF EN 15804+A1
EPD Italy	Wooden floors	Pavimenti in legno Collezione Garbelotto	A1-A3, A5	2021	-	Parchettificio Garbelotto S.r.l.	EN 15804+A1

9.4.3.1 Cut-off methodology

The different EPDs use the same cut-off methodology as prescribed by EN15804 and EN 16485.

9.4.3.2 Allocation methodology

In different EPDs different allocation procedures are used. In general co-products are allocated based on economic value. The IBU EPDs specifically mention that allocation within the forestry value chain is based on the publication of Hash 2002 and its update by Rüter & Albrecht 2007 (166

9.4.3.3 Losses in production chain

None of the EPDs explicitly states anything regarding production losses except for that losses are allocated based on their market price.

9.4.3.4 Mass balance of wood

All EPDs display the mass balance of the materials in the declared functional unit. The wood products are put onto the market with a certain moisture content. This moisture content can decrease (or increase) over the product life time. Therefore, close attention must be given to the end of life incineration mass for energy recovery. The energy recovery lower heating values are based on dry materials.

9.4.3.5 End of life scenario

It is notable that all of the analysed EPDs from IBU state a 100% energy recovery upon incineration. One EPD mentions that landfilling wood waste is impermissible, although there is no mention as to why this strict exclusion is imposed. In the analysed EPDs, the energy recovery causes environmental benefits (from spared natural gas) in module D.

The Environdec EPD on 'Thermowood' presents three different end of life scenario's, recycling, incineration and land fill. For each phase the A1-A3, C1 and C2 carbon emissions are declared to be the same. In A1-A3 there is a biogenic carbon uptake of 744 kg. When recycling this 744 kg of biogenic CO_2eq. is emitted and in module D -745 kg CO_2eq. has been declared. This means that there is a full life cycle negative biogenic CO_2eq. In the scenario of landfilling the biogenic emission in C4 is 1780 kg, which is considerably higher than the uptake in module A1-A3. The reason behind the high biogenic CO_2eq. emission from landfill is not explained, nor is explained why the full life cycle in the recycling scenario can be negative.

9.4.3.6 CO_2 emissions

It is notable that 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. 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. In the Dutch PCR "bepalingsmethode milieuprestatie bouwwerken", a strict method is prescribed to declare benefits from energy recovery of incineration. The method is based on the energy content (Lower Heating Value) and the efficiency of the average Dutch installation including a mix to thermal and electrical energy outputs.

To assess the sensitivity of the end of life scenario on the issue of the saved emissions a comparative LCA calculation has been made on two products, and compared to the declared values for modules C3 and D in the EPD. See Table 9.14.

Table 9.14 Comparative calculation saved CO_2eq emissions

Product	C3 EPD	D EPD	Sum	C3_NL	D_NL	Sum	%
Medium Density Fibreboards EGGER MDF / Mitteldichte Faserplatten (m^3) - Climate change – Biogenic - (kg. CO2 eq.)	1100	-1,61	1098,39	1075,053	-419,004	655,996	60
Wood fiber panels (m^3) - Climate change (only total available on EPD) – (kg. CO2 eq.)	270	-184,5	85,5	243,9319	-95,0729	148,859	174

The comparative calculation was made with the following scenario (Dutch standard for wood 'clean');

- End of life – incineration is 85%
- End of life – landfill is 10%
- End of life – recycling is 5%

The emissions in C3 are calculated with Ecoinvent background data for municipal incineration and sanitary landfill. The (saved)emissions in module D are calculated with the Ecoinvent background data for planing and wood chips (recycling) and avoided energy based on the LHV (lower heating value) of 13,99 MJ/kg and saved emissions for a Waste Incineration Plant-renewable source ("AEC" for energy recovery).

Although the comparative LCA calculations are limited to modules C3 and D and not the full life cycle, the results from Table 9.14 clearly indicate that the aspect of correctly accounting (without judging which PCR that is) for saved emissions is a highly sensitive part of the LCA model, and therefore for the EPD as a whole. It should be noted that module D is not technically a part of the life cycle and normally should not be summed up with the total results when considering an EPD. Here it was done to be able to track the total carbon balance and provide insights in possible discrepancies. Additionally, developments in EU standards and legislation show a clear shift to inclusion of Module D at the building/project level. An assessment on a combined product or project level demands the same data quality and scenario plausibility as the other modules. In the Dutch system for sustainable buildings this is already implemented on a legislative basis, and therefore module D is added to the summation of the results on a project/works level.

9.4.3.7 Possible omissions

To allow biogenic carbon neutrality to be accounted for wood, the material must be originating from forests that are operated under an established sustainable forest management certification according to EN16485 (see also section 9.4.2.2). Only part of the EPDs 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 under the application of this standard.

9.4.3.8 Biogenic carbon flow

Only new EPDs that are based on the 15804+A2 standard separate the global warming potential in biogenic and fossil carbon dioxide equivalent emissions. All wood products in the researched EPDs, that are based on the A2 methodology, enter the system (module A1) as a negative (carbon storage). In module C3 a comparable amount of carbon dioxide equivalent is released. However, it is notable that the value for module C3 is not exactly the positive of module A1. This difference must be derived from other processes in the EPD. Also in modules A5, B3, C2 and D small amounts of biogenic carbon impacts are declared. It would require investigation of the underlying LCA studies (often not publicly available) to understand these imbalances between modules A1 and C3, and the declared biogenic impacts in modules A5, B3, C2 and D (outside the scope of this study).

For example, Table 9.15 provides an overview of the declared biogenic carbon flow for three of the selected EPDs

Table 9.15 Comparative declared biogenic carbon flows

Product	A1-A3 (kg. CO2 eq.)	C2 (kg. CO2 eq.)	C3 (kg. CO2 eq.)	D (kg. CO2 eq.)	Total (kg. CO2 eq.)
Medium Density Fibreboards EGGER MDF / Mitteldichte Faserplatten (m^3)	-1090	-3,98E-3	1100	-1,61	8,386
HASSLACHER CROSS LAMINATED TIMBER/ Brettsperrholz HASSLACHER CROSS LAMINATED TIMBER (m^3)	-754	-1,67E-3	750	-1,42	-5,422
Brannpanel Natur - Brannimpregnert Thermowood av furu (m^2)	-15,1 7,81 (IOBC)		15,1 1,49 (IOBC)	-0,785	8,515

As stated in section 3.2;
"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.. Not taking into account carbon omissions through material substitution, the system cannot be carbon neutral, as emissions caused by transport and processing add to the natural emissions from the natural forest system itself and therefore exceed carbon sequestration levels."

With this in mind, Table 9.15 shows for one of the selected EPDs that there is an overall negative biogenic CO_2 impact. It is unclear in the EPD how this is calculated and/or justified.

The EPD under the Norwegian EPD program, Brannpanel Natur, declares a strict -1 / +1 approach on the biogenic CO_2 stored and emitted in the product life cycle balance. In this EPD, there is a second biogenic emission declared, the "instant oxidation" (IOBC) which is used when biogenic carbon in products is accounted as an emission at the time of harvest and thus no storage in products are accounted for.

9.4.3.9 PCR consistency

No inconsistencies with the applicable PCR have been noticed in the EPDs. Several of the IBU EPDs apply allocation based on the publication of Hasch and its update by Rüter & Albrecht (166). This publication has not been assessed for discrepancies with the European standards.

It should be noted that the different PCRs can lead to different and incomparable EPD results. For example EPDs that are based on EN 15804+A1 have no specific rules for biogenic carbon and can be considered cradle-to-gate. This would not be allowed for EPDs that are based on the EN 15804+A2 version.

9.4.4 Conclusions on EPD assessments

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

Proper alignment of these issues in PCR standards 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).

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10 Accounting for temporary carbon storage in LCA

10.1 Introduction

Biobased materials may have an important role in mitigating climate change and resource depletion. Materials from a biological source are virtually un-depletable when sustainably managed and carbon emissions belong to a short carbon cycle, as opposed to materials from fossil sources. Life cycle assessment (LCA) is an important tool to support and to quantify the environmental claims and benefits of biobased materials. International standards for LCA offer generic recommendations on the evaluation of environmental impacts of products and services, but often do not address the more complex details that are relevant to the life cycle of biobased materials. One example of this is the storage of biogenic carbon. This is critical for quantifying the GHG emissions from biobased products as compared to conventional alternatives (167).

Whether or not to account for biogenic carbon storage is an ongoing academic debate. On the one hand biogenic carbon storage should be excluded from impact analysis, because it is most often reversable in nature and will inevitably lead to carbon emissions in the future. On the other hand, it should be accounted for as it can offset current anthropogenic carbon emissions and it can delay radiative forcing. The possible benefits of carbon storage highly depend on the chosen time horizon and future atmospheric GHG concentrations and anthropogenic carbon emissions.

10.2 General assessment methods of carbon sequestration

The concept of biogenic carbon storage is controversial. International standards for LCA offer little direction on how the environmental effects of such storage can be quantified. There are generally 2 approaches identified.

- Biogenic carbon is considered carbon neutral and is to be excluded from impact analysis
- Biogenic carbon is accounted for as carbon storage with, or without quantified benefits

The mentioned approaches are often called the 0/0 and -1/+1 methods respectively.

In the 0/0 method biogenic carbon is considered to be part of a short carbon cycle with negligible effects on radiative forces. The biogenic carbon flows (both uptake and emission) are not included in the system and are therefore not registered. One exception is the formation of methane, for instance as a result of waste treatment. This is due to the fact that methane (CH_4) has a much larger influence on radiative forces than carbon dioxide (CO_2).

The second approach, which is referred to as the -1/+1 approach tracks all biogenic carbon flows over the product life-cycle. In this approach both the biogenic carbon uptake (-1) and the release (+1) fall within the system boundary and are considered.

The main advantage of the -1/+1 approach is that it gives a complete overview of the carbon flows (4). However, there is a risk of misleading results when only considering the production stages A1-A5 (cradle-to-gate), as this would result in a negative carbon emission. The 0/0 approach on the other hand can be calculated fairly for both cradle-to-gate and cradle-to-grave. However, it does require a distinction between biogenic CO_2, biogenic CH_4 and fossil carbon emissions.

In the following diagram we illustrate the carbon flows with the different system approaches.

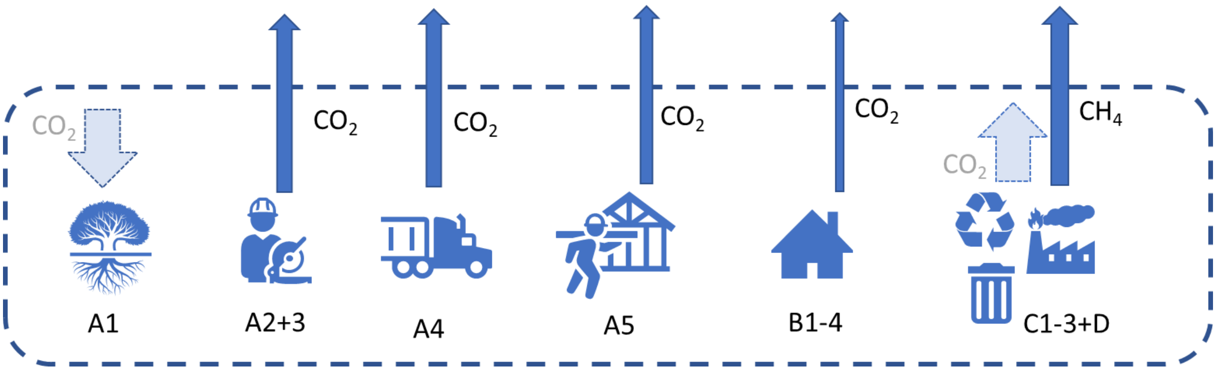

Figure 10.1
Illustration of carbon flows and registration in the 0/0 method. The main carbon flow (biogenic) is considered in balance and is not registered. Any fossil carbon flows, or biogenic methane leaving the system is registered.

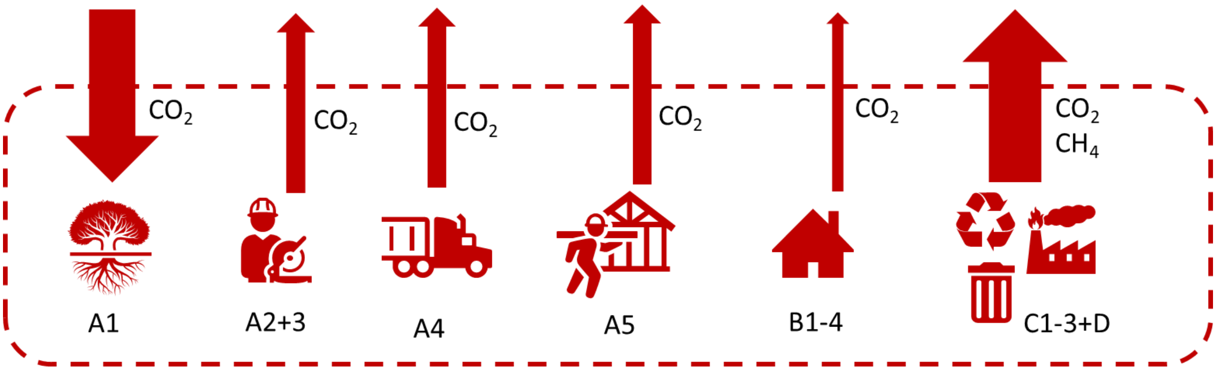

Figure 10.2
Illustration of carbon flows and registration in the -1/+1 method. The main carbon flow (biogenic) is fully registered as flows entering and leaving the system. Fossil and biogenic carbon emission are treated equally.

10.3 Official assessment methods for carbon sequestration

The two mentioned LCA approaches have two main drawbacks. First of all, they do not consider the timing of the carbon fluxes. For instance, carbon uptake is considered to be a single event while in reality it is a process of years. Secondly, it assumes carbon neutrality of forests. Both aspects represent a limitation of these methods when assessing the impact of biobased products (168). In the following sections several common assessment methods for carbon sequestration are introduced. All methods are critically reviewed on scientific accuracy and practical implication (169). These methods allow to account for temporary storage but as such form a system outside (or on top of) the main GWP calculation.

10.3.1 LCA based methods

ISO 14040/14044
The ISO 14040 and 14044 require biobased materials to be carbon neutral. This means that the carbon balance over the entire life cycle must equal 0, so that carbon uptake and emission are in balance. This however does not account for possible system benefits, as the system boundaries in so called attributional LCA's are restricted to the products' life cycle.

There have been several attempts to account for bio-based carbon storage. Some initiatives call for carbon neutrality, whilst most initiatives do take storage into account. In some approaches emissions are time dependent, with the time that carbon is stored being an important factor. Only a few initiatives also provide a weighing factor for the time dependency.

ISO 14067 – carbon footprint of products
The standard for carbon footprint of products by ISO 14067 (2012) states that when calculating the environment footprint for a product's full life cycle (Cradle-to-Grave) all emissions and removals (biogenic and fossil) must be taken into account. The method does not account for time that carbon is stored. This means that biogenic carbon storage in biobased products should be considered as carbon removed from the atmosphere. If the use or disposal treatment leads to emissions within 10 years of initial uptake, they should be treated as if they had occurred at the beginning of the assessment period. In addition to the standard calculations it is possible to calculate the effects of delayed emissions if the time between uptake and emission is more than 10 years. The findings are to be reported separately, with it being mandatory to report the GHG emissions without the time dilation and the reasoning for the chosen method of qualifying the carbon storage effects. The standard gives no specific approach for taking into account the carbon storage effects. In short this method can be considered a nuanced version of the -1/+1 method, with the possibility of additional calculations regarding temporary carbon storage.

ILCD Handbook

The International Reference Life Cycle Data System (ILCD) Handbook put forward a method that accounts for time when assessing the effects of temporary (biogenic) carbon storage on global warming. In line with the IPCC, the ICLD method works with a timeframe that distinguishes between carbon that is released within a 100 year period and carbon that is released more than a 100 years after the biobased product was produced. For carbon that is released within the first 100 years the credit of temporary storage is to be calculated by multiplying the mass [kg] of embodied carbon (expressed as kg CO_2-eq) with the number of years of carbon storage, divided by 100. This equals to a weighing factor of 1% per year. Carbon released after 100 years is generally not taken into account in LCA results and is treated as permanent carbon storage. To ensure that release of carbon after 100 years is not completely ignored, it should be reported separately. In short the method quantifies the effects of temporary carbon storage on climate change by a weighing factor of 1% per year that carbon is stored. The rational for this is that for every year carbon is stored a part of it (1%) falls beyond the time horizon of 100 years.

PAS 2050

The British Standards Institution (BSI) developed the PAS 2050, which includes the concept of biogenic carbon storage. It considers a timeframe of 100 years, similar to that of the IPCC and the EC. All carbon emissions and removals (both fossil and biogenic) within this 100 year timeframe are quantified and treated equally. The effects of a delay in emissions may be taken into account, but not earlier than 1 year after the product is finalized. To account for the delay in emissions the same approach is applied as in the ILCD Handbook. One exception to this is when all carbon is released in a single event between year 2 and year 25 after finalization of the product. One such example of this is incineration. In calculation the PAS introduces a multiplication factor 'm'. The factor is based on the removal rate of carbon from the atmosphere. This factor is set to 0.76, based on calculations of the University of Surrey (Roland Clift, 2008). If all carbon emissions occur in the first year, they are treated as a single emission event with a weighing factor of 1. If all carbon emissions occur as a single emission event between the first year and the 25th year, the weighing factor is calculated by multiplying 0,76 with the number of years carbon is stored, divided by 100 years.

The used calculations of the University of Surrey find their basis in the approach to accounting for delayed release, as illustrated in Figure 10.3. Other contributions are the methods proposed by Moura-Costa and Lashof (170)(171).

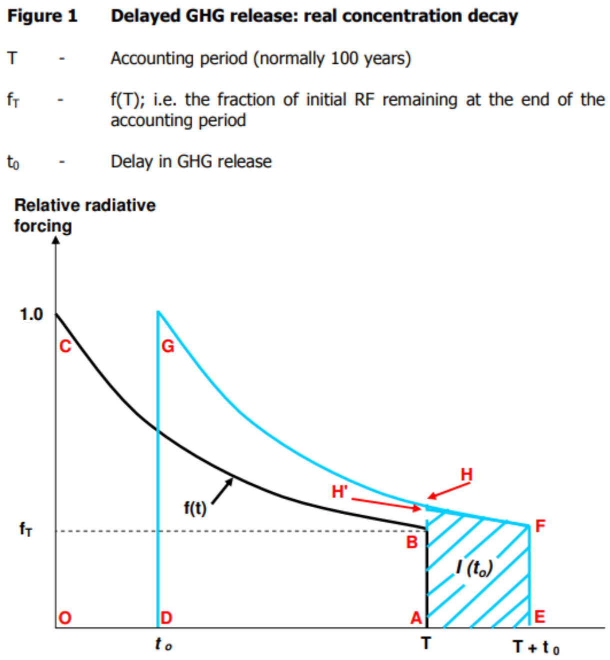

Figure 10.3
Delayed GHG release, from: University of Surrey (172)

10.3.2 Other accounting/reporting methods

GHG Protocol Initiative

The GHG Protocol Initiative of the World Resources Institute and the World Business Council for Sustainable Development is a standardized method for the inventory of GHG emissions of all, including biobased, products (173). For Cradle-to-Gate the method gives credits for biogenic carbon storage similar to the Lead Market Initiative, where biogenic carbon is taken out of the equation (0/0 method). For Cradle-to-Grave the amount of carbon released throughout the use and disposal of the product needs to be accounted for. Embedded carbon that is not released in the atmosphere, such as in ashes of disposed wood are to be subtracted. The reasoning for this is that not all carbon is released into the atmosphere. Some carbon that is embedded in the ashes are not expected to be released under the anaerobic conditions of a landfill. In the case of intermediate biobased materials the biogenic carbon stored in products need to be reported. The method does not include a weighing factor for delayed, offset or avoided emissions due to (temporary) biogenic carbon storage. This method is widely accepted and follows a nuanced version of the 0/0 and the -1/+1 methods.

IPCC Tier 2 approach
The 1996 IPCC Guidelines did not provide methods for estimating carbon held in HWP, and recommended, for the purpose of basic calculations, a default assumption expressed as "... that all carbon biomass harvested is oxidised in the removal [harvest] year". This was based on the perception that HWP stocks are not changing. Given that inputs do not in general equal outputs and that carbon can remain stored in HWP for extended periods of time, this storage time was taken into account in the later IPCC Guidelines for National Greenhouse Gas Inventories (174).

Instant oxidation of HWP was assumed for Commitment Period 1 (CP1) of the Kyoto Protocol on the basis that, at a first approximation, the global pool was neither increasing nor decreasing. For CP2, IPCC (175) still allows this as a Tier 1 approach where transparent and verifiable data on HWP are not available. However, when transparent and verifiable data are available, changes in the HWP pool are to be accounted for using a first-order decay function. Tier 3 applies when country-specific half-lives and/or methodologies are available. Otherwise Tier 2 applies. When Tier 2 is applied, default half-lives of 35 years, 25 years and 2 years are to be used for sawn wood, wood panels and paper, respectively (174). Most EU member states apply a Tier 2 approach.

The European Commission's Lead Market Initiative
The Lead Market Initiative states that biogenic carbon in biobased materials should be deducted when calculating the total carbon emissions caused by the product (Cradle-to-Gate). There is no guidance given for the temporary storage of carbon during the use phase. The method is often called a 0/0 method, as biogenic carbon is taken out of the equation. The reasoning is that biogenic carbon is part of the short carbon cycle with insignificant radiative forcing.

ADEME's methodology for bio-based materials
The French Environmental and Energy Management Agency (ADEME) argues that biogenic carbon storage in biobased products should be considered as carbon neutral. Within the methodology it is assumed that the average lifespan of biobased materials does not typically exceed 10-20 years. This would make it reasonable to assume that the benefits of carbon storage are negligible. The methodology is commonly applied for bioenergy products. For products with a longer lifespan the carbon neutrality principle is a conservative approach that disregards possible benefits of long- and midterm carbon storage. The method is often also called a -1/+1 method, as carbon uptake in the production phase and emission in the use and disposal phase is considered equal, or neutral. The reasoning for this is that biogenic carbon will eventually find its way back into the atmosphere. This particularly holds true for short lived products (<20 years).

10.4 Unofficial assessment methods for carbon sequestration

The mentioned common methods for carbon sequestration either consider carbon neutrality (0/0 and -1/+1) or calculate temporary carbon storage through (linear) discounting as an approximation of the non-linear atmospheric uptake and decay of GHG. To overcome the shortcomings of the static and linear approaches, some methods allow consideration of the temporal dynamics of the carbon fluxes and forest growth. The dynamic LCA methods can be distinguished into two groups. Those considering tree growth happening before wood harvest, and those considering tree growth happening after wood harvest. These methods also tie in with dynamic LCA as mentioned previously in chapter 9.

In the following diagrams both approaches are illustrated. These illustrations are based on Hoxha, 2020. In follow up several innovative approaches are presented (168).

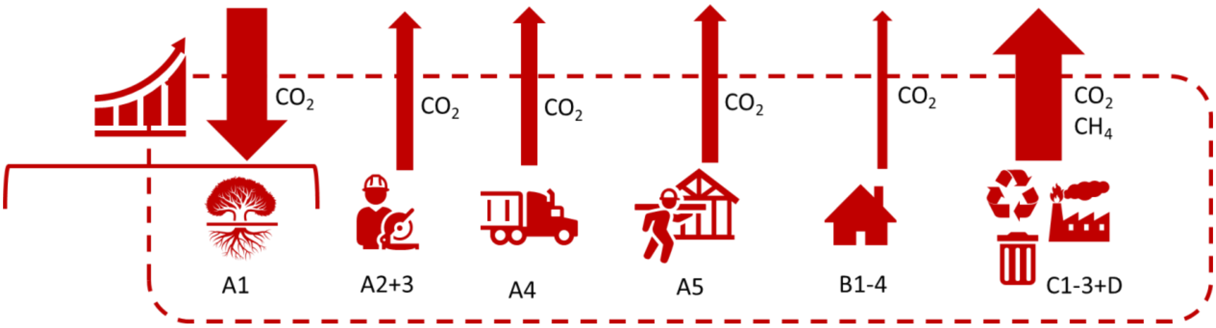

Figure 10.4
Illustration of carbon sequestration considering carbon uptake to take place prior to harvest (< T=0).

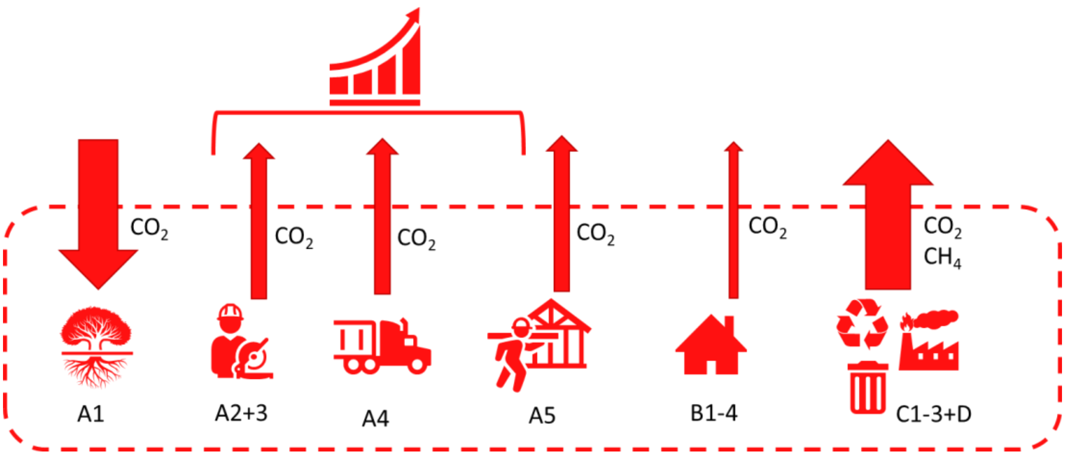

Figure 10.5
Illustration of carbon sequestration considering carbon uptake to take place from harvest (>T=0).

One such approach is from Levasseur et al (176). It proposes a dynamic method to consider time in LCA. The method is based on the use of time-dependant characterization factors (DCF). DCF's can be applied to the dynamic life cycle inventory and can be used for any time horizon. The method does not distinguish between biogenic and fossil carbon and can be both applied with tree growth pre- and post-harvest (176).

In 2011, Cherubini et al introduced an approach that considers biogenic carbon impact based on specific characterization factors (GWP_{bio}) (177). The specific characterization factor takes into account the rotation period of the forest (177) (178). The method was improved in 2012 by the same team to also include the effect of delayed carbon emissions due to temporary biogenic carbon storage (179). Guest et al., extended the method in 2013 with the inclusion of a more accurate estimation of the net carbon emissions when biomass is used as an energy source at end-of-life (180).

In extension of the method of Cherubini & Strømman, Pingoud et al developed the $GWP_{net\text{-}bio}$ factor late 2011 (181). 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 to take land-use and land-use change (LULUC) into consideration (181). The GWP is further modified to also include the use of biomass and the displacement of functionally equivalent fossil- or mineral based products using the displacement factors developed by Sathre & O'Connor in 2010 (168) (182).

A similar approach to that of Levasseur is introduced by Kendall (183). It deals with the timing of carbon fluxes by use of the Time Adjusted Warming Potential (TAWP) in addition to the conventional Global Warming Potential (GWP). In the conventional calculation of GWP, the warming potential of a gas is calculated with the cumulative radiative forcing (CRF) within a fixed time horizon of 100 years. In the TAWP the warming potential is calculated by integrating the CRF only for the years that the gas is in the atmosphere within the time horizon (183).

A variation on the GWP_{bio} approach is the alternative weighting factor (WF) method proposed by Väisänen (184). The WF method is calculated similarly to the GWP_{bio}, but considers carbon uptake of forests with a simple linear function. The temporal dynamic of biogenic carbon fluxes are assumed to cumulatively happen at the time of felling as a unique pulse emission (168).

A slightly different approach comes from Vogtländer (185). The approach is based on the global carbon cycle with a special interest in land-use change. They argue that the methods of the ILCD and PAS2050, with discounting of CO_2 based on the atmospheric lifetime of CO_2 leads to an overestimation of the benefits of temporary carbon storage. In their approach the credits for carbon storage can only be allocated when there is both a global growth of forest and a growth of the application of wood in buildings (185). The method does not discount delayed emissions. It also relies heavily on accurate information on land transformation (168).

In 2016 Helin et al proposed $GWP_{bio\text{-}product}$ (186) as an alternative to the mentioned $GWP_{net\text{-}bio}$ of Pingoud et al (181). This characterization factor does not include displacement, but does include the effects of temporary storage as well as the impact of harvest. The impact of harvest considers the impact of changes in atmospheric carbon between harvested and undisturbed biomass (186).

The methods mentioned above all address specific limitations of the two main methods (0/0 and -1/+1). It is however worth mentioning that none of the methods can be considered a holistic approach including all limitations.

10.5 Critical aspects of carbon sequestration

Some aspects of carbon sequestration are considered critical: time horizon, the assumption of sustainably managed forests, land use / land-use change (LULUC) and end-of-life scenario's. In the following sections we elaborate on these critical aspects.

10.5.1 Time horizon

One of the critical aspects of carbon sequestration is the time horizon, often considered to be 100 years. The choice of time horizon is an important aspect in the assessment of temporary carbon storage. The choice for 100 years is logical as many policies, such as the Kyoto protocol handles a similar horizon. The idea behind the 100 year time horizon is to provide a relative weighting of the different GHG's. Despite it being a somewhat arbitrary choice from a scientific perspective, it has great implications on a policy level. A shorter time horizon would give more weight to delayed emissions, while a longer time horizon would diminish the sense of urgency. An alternative to the fixed 100 year time horizon is a variable time horizon. With a variable time horizon the impact is assessed over a time horizon beginning when the first emission occurs and finishes in e.g. the year 2100. It corrects for the service life in which carbon is stored in a product system and more accurately calculates emissions of long lasting biobased materials. This would however diminish the comparability of products calculated in different years. An assessment done next year should for the sake of consistency use the same characterisation factor as an assessment done today (187). So far, there is no scientific consensus on the use of different, and/or dynamic time horizons in LCA. The 100 year time horizon remains by far the most commonly used horizon.

10.5.2 Sustainable forestry assumption

None of the mentioned official standards considers the (un)sustainability of forestry. In most cases sustainable forestry is assumed[6], possibly overestimating the positive effects of the use of biomass on the GWP. As previously mentioned, the ISO 21930 and the EN 16485 state that the CO_2 sequestration of sustainable managed forests is characterized by -1 kg CO_2-eq/kg CO_2. For unsustainably managed forests this value is 0. The problem however lies with the determination of sustainably managed

6 Within the definition of sustainably managed forestry, carbon neutrality is assumed.

forests. One way to determine sustainably managed forests is by account of art. 3.4 of the Kyoto protocol, where all forests are considered sustainably managed by default when located in a country that reports on the protocol. The certifications FSC and PEFC can also be useful when demonstrating the sustainable management of forests. It has however been proven to be sensitive to fraud in the past (UNEP-WCMC, (188)). The EN 15804+A2 approaches sustainability of wood by distinguishing between native and non-native forests. With this distinction native forests are always considered non sustainable, while non-native (production) forests are always considered sustainable and therefore carbon neutral. This however does not hold true when taking into account land-use and land-use change, mentioned in the next section. The approaches by Vogtländer (185), Cherubini (178), Pingoud (181) and de Rosa (189) poses a better understanding of sustainably managed forests and the resulting carbon fluxes (168). However, this has so far not been included in any of the official methods.

10.5.3 Land use and Land use change (LULUC)

In more recent work land use and land-use change (LULUC) is gaining interest as it is presumed to have major impact on carbon sequestration. Whilst the direct carbon exchanges of biobased materials are generally well understood, the indirect carbon exchanges through land use of and land-use change are often underestimated in literature (169) (190). Evidence suggests that non-human managed land could store up to 49% more carbon than human-managed land (190). Furthermore, as previously mentioned, production forests hold less biogenic carbon in soil and root systems than natural forests (191). As the demand for timber increases, the land-use for the production of timber will likely also increase. Depending on the land transformation (grassland to production forest, or natural forest to production forest), the indirect carbon emissions as a result of LULUC can vary greatly (192)(193)). It is therefore crucial that LULUC is both fully understood and fully included in the life cycle assessment of biobased products where land-use is significant. The more recent ISO-21930 and the EN-15804+A2 provide characterisation factors for LULUC based on the sustainability of the forest management. Unsustainably managed forest has a characterisation factor of 1 kgCO_2-eq/kgCO_2, while the sustainable managed forest has a factor of 0 kgCO_2-eq/kgCO_2. This is a rough distinction between sustainable and unsustainable forest management, it however does not provide a full image of the complex interactions of LULUC. As indirect land-use change methods are still under development, the calculation of indirect land-use and land-use change is currently not required by LCA standards. This results in a gap in carbon sequestration effects with the risk of misinterpretation.

To overcome this lack of data de Rosa (189) proposed a simplified time-dependant model for forest carbon fluxes in LCA. The method is based on the older CO_2FIX models (194). The model includes a carbon pool both above and below ground, dynamic biomass growth, dynamic biomass decomposition, both above and below ground and several characteristics of forest management, such as rotation, stand time, thinning frequency and intensity. This model has so far not been applied in LCA work.

10.5.4 End of life

At end-of-life wooden products can either be landfilled, incinerated with or without energy recovery, recycled or re-used. In the LCA standards the impact of landfilling or incineration is fully assigned to the product system. In the case of re-use, recycling and incineration with energy recovery the benefits are shared between the current product system and the next product system. There are 3 main types of allocation approaches that can be applied.

The first approach is the recycled content or cut-off approach. It allocates the benefits of recycling to the product system that makes use of these secondary resources. It is commonly used in the ISO 21930, EN 15804+A2 and the EN 16485 where re-use, recycling and energy recovery are reported in module D. This module D falls outside of the product system boundary, but are reported separately.

The second approach is referred to the closed-loop approximation. In this approach benefits are fully allocated to the product system. In the PAS 2050 and the GHG protocol both the recycled content and the closed-loop approximation can be used. The closed loop approximation is mainly used for recycled materials that retain the same inherent properties as the virgin materials. The avoided impact of the production of a new construction product can be subtracted from the life cycle impact of the first building.

The third method consists in sharing the benefits and loads of recycling between the first and second life cycle. This is the preferred approach of the PEF standard (195) and the related PEFCR's. In this approach the allocation factor are applied following the circular footprint formula. The choices in the calculation of end-of-life can greatly influence the results of LCA on i) benefits of re-use and recycling and ii) substitution effects of end-of-life energy recovery in the case of incineration (168). It is expected that the method posed with the PEF standard will become the most dominantly used.

10.6 Review on available methods

There have been few critical reviews of LCA methods for handling biogenic carbon in buildings.

E. Hoxha et al. (169) reviewed the methodological differences between the most commonly used methods and recommend standards for biogenic carbon accounting in buildings. For comparison of 4 different LCA approaches a case study has been used. The LCA approaches included in the study are: the 0/0 method, the -1/+1 method and the dynamic modelling method. In the dynamic modelling carbon uptake pre- and post-harvest was considered. Whilst both the 0/0 method and the -1/+1 resulted in the same GW score of 20,7 kgCO_2-eq/m^2/yr, the dynamic method resulted in a significantly higher GW score of 26,7 kgCO_2-eq/m^2/yr. The review did not consider sustainable forestry with thinning, where carbon uptake is at all times in balance with carbon output in the form of biomass (and other emissions from forestry). It did however take land use and land use change (LULUC) in consideration. Brandão et al (167) have critically reviewed six available methods for accounting carbon sequestration and temporary carbon storage in biobased products. They conclude that the benefits of temporary carbon storage highly depend on the time horizon adopted when assessing the climate change impacts (167).

Most recently a consortium of research institutes (168) have reviewed the most novel methodological developments in carbon sequestration of biobased products as part of a much wider research on the climate benefits of the use of harvested wood products in the construction sector.

Based on their review of the established LCA standards and several innovative approaches, they concluded a lack of consistently and consensus. Their recommendation to the European Commission includes the development of a single methodology for measuring embodied carbon and biogenic carbon content of wood products used in construction. The single method should consider the strengths and weakness of the available standards and approaches mentioned in literature. They propose a similar approach to that of Hoxha et al. (169) where carbon storage is modelled dynamically. This appears to be most consistent with available academic evidence. So far these recommendations have not led to a new holistic and single methodology.

10.7 Current position on temporary carbon storage in LCA

From a scientific perspective, temporary carbon storage has potential in contributing to the set climate objectives such as the Paris Climate Agreement or the Fit for 55 targets of the European Union. However, the potential benefits of temporary carbon storage in HWP cannot be seen separate from the prerequisite of sourcing the biomass from sustainably managed forests (i.e. net growth is in balance with or exceeds harvested biomass).

By capturing carbon in biomass and storing it for a time period of more than 50 years the radiative forcing effects can (temporarily) be tampered. These benefits are additional to the substitution effect of reduced use of carbon intensive products. Reaching the set climate targets in time is however a political decision. From a scientific perspective emissions after the years 2050 and 2100 matter as well as emissions before this deadline.

From the different methods available for accounting temporary carbon storage in LCA, the one that includes the $GWP_{net\text{-}bio}$ factor by Pingoud et al. (181) offers the most holistic approach as it includes LULUC effects. We would argue however that the benefits of carbon storage, as proposed in PAS 2050 and the ILCD handbook are a fair and practical solution for accounting in LCA, and adjust for a high degree of uncertainty in the End-of-Life scenario's.

At the time of writing this report, IPCC's Working Group III (Mitigation of Climate Change) is finalising its 6^{th} Assessment Report. Unfortunately, the draft of this report (193), although dedicating sections on bioeconomy and carbon storage, does not provide a scientific consensus on how to account for (benefits of) temporary carbon storage within the context of life cycle assessment methodology.

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11 Temporary carbon storage in HWP in construction

11.1 Introduction

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 (196). As a consequence, the same holds true for utilising harvested wood products in the construction sector as a temporary carbon sink.

11.2 Literature review of temporary carbon storage in biobased materials

In order to form a position on the potential of temporary carbon storage in HWP in construction, we conducted a state-of-the-art literature review on the topic of temporary carbon storage in the biosphere and biobased materials.
In this review based upon peer-reviewed literature search in ResearchGate and Google Scholar, the focus is 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. The literature review of these publications is summarised in Table 11.1.

While literature has been found with a critical stance on temporary carbon storage (notably Kirschbaum (197) and Levasseur et al (198), as well as a positive stance by Knoke & Weber (199), most sources are neutral on the subject.

Table 11.1

Literature review of scientific publications > 2000 assessing temporary carbon storage (in biomaterials)

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
Temporary carbon sequestration cannot prevent climate change	Kirschbaum, M	2009	(210)	Storing carbon in biosphere sinks can reduce atmospheric CO2 concentrations in the short term. However, this lowers the concentration gradient between the atmosphere and the oceans and other potential carbon reservoirs, and consequently reduces the rate of CO2 removal from the atmosphere. If carbon is released again from that temporary storage, subsequent atmospheric CO2 concentrations will, therefore, be higher than without temporary carbon storage.	Criticizing	The author is of the opinion that the trade-offs described cannot be overcome and will – on the whole – lead to a negative impact on climate change.
Assessing Temporary Carbon Storage - in Life Cycle Assessment and Carbon Footprinting Outcomes of an expert workshop	Brandão, M., Levasseur, A. 2011,. JRC	2011	(200)	Climate benefits of an isolated temporary carbon storage event arise solely when time preferences are reflected in the method used. This means that accounting for any benefits relies on value-laden methodological decisions, such as the choice of a time horizon beyond which impacts are not considered. Indeed, the longer the time horizon adopted for integration of radiative forcing or impacts, the lower the benefits are from temporary carbon storage. This will only be different if the temporary storage is repeated, essentially becoming a permanent removal from the atmosphere. If temporary storage is considered then it is common practice to adopt a 100-year time horizon using the Global Warming Potential index. However, no clear consensus has been reached from these discussions regarding whether or not to account for temporary carbon storage in general and, if so, which method to employ. The choice of a 100-year time horizon equally remains controversial Since the benefits given to temporary carbon storage rely on value-laden choices, if considered then it is important to make them explicit and transparent when using any accounting method. Both short and long term time horizons should be considered. It was suggested to do more research in order to improve climate-change modelling in LCA to include two other indicators (i.e . instantaneous temperature increase and rate of temperature increase), since they provide information on different types of climate-change impact, and can lead to different conclusions than the single use of cumulative radiative forcing. Furthermore, research is warranted on the dynamics of the carbon cycle (e.g. changes in sinks – biospheric, atmospheric and oceanic – are interdependent and cannot be assessed in the same linear way as fossil emissions with GWP). This is because any change in biospheric carbon stocks may be partially or totally compensated by the inverse process from other sinks (e.g. oceans), so this dynamism needs to be addressed.	Neutral (contributors both criticize and support)	

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
Valuing temporary carbon storage	Levasseur, Annie & Brandão, Miguel & Lesage, Pascal & Margni, Manuele & Pennington, David & Clift, Roland & Samson, Réjean.	2012	(198)	When using metrics with finite time horizons, the impact of a fossil-fuel emission on climate change can be completely offset by the sequestration and storage of an equivalent amount of carbon for a period of time equal to the adopted time horizon. Thus, temporary carbon-storage projects (for example, afforestation) can help mitigate climate change impacts. However, these should not be considered equivalent to avoided fossil-fuel emissions, because carbon is not kept out of the atmosphere permanently. Explicit and justified value choices by decision-makers should govern the selection of an appropriate time horizon, to make robust and consistent choices; special attention is warranted to its implications and effects on the results, so that temporary mitigation activities are not favoured over permanent actions	Criticizing	Storing carbon for a given number of years is equivalent to delaying an emission by the same number of years, hence decreasing the period of time over which its impact is considered. The choice of any time horizon (including infinity) is a value judgement rather than a scientific decision.
Need for relevant timescales when crediting temporary carbon storage	Jørgensen, Susanne & Hauschild, Michael	2012	(201)	Both short- and long-term perspectives should be considered when crediting temporary carbon storage, addressing both acute effects on the climate and the long-term climate change. It is however essential to distinguish between short- and long-term mitigation potential by treating them separately and avoid that short-term mitigation is used to counterbalance long-term climate change impacts from burning of fossil fuels.	Neutral	The global carbon cycle shows timescales of thousands of years for the transport of carbon from the atmosphere to pools beyond the near-surface layers of the Earth, from where it will not readily be re-emitted as a response to change in near-surface conditions. Compared to such timescales, the use of the 100-year accounting period appears hard to justify. The use of the 100-year accounting period can cause long-term global warming impacts to be hidden by short-term storage solutions that may not offer real long-term climate change mitigation. Obtaining long-term climatic benefits is considered to require storage of carbon for at least thousand years. However, it has been proposed that there may exist tipping points for the atmospheric CO2 concentration beyond which irreversible climate changes occur. To reduce the risk of passing such tipping points, fast mitigation of the rise in atmospheric

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
						greenhouse gas concentration is required and in this perspective, shorter storage times may still provide climatic benefits.
The potential contribution to climate change mitigation from temporary carbon storage in biomaterials	Jørgensen, Susanne & Hauschild, Michael & Nielsen	2015	(202)	Temporary carbon storage in biomaterials has a potential for contributing to avoid or postpone the crossing of a climatic target level of 450 ppm CO2e, depending on GHG concentration development scenario. The potential mitigation value depends on the timing of sequestration and re-emission of CO2. The suggested CTP approach enables inclusion of the potential benefit from temporary carbon storage in the environmental profile of biomaterials. This should be seen as supplement to the long-term climate change impacts given by the global warming potential which does not account for temporary aspects like benefits from non-permanent storage in terms of avoiding a critical climatic target level.	Neutral	The potential mitigation value depends on the timing of sequestration and re-emission of CO2
An issue of permanence: Assessing the effectiveness of temporary carbon storage	Herzog, Howard & Caldeira, Ken & Reilly, J	2003	(204)	Our results show that the value of relatively deep ocean carbon sequestration can be nearly equivalent to permanent sequestration if marginal damages (i.e., carbon prices) remain constant or if there is a backstop technology that caps the abatement cost in the not too distant future. On the other hand, if climate damages are such as to require a fixed cumulative emissions limit and there is no backstop, then a storage option with even very slow leakage has limited value relative to a permanent storage option.	Neutral	See abstract/conclusion
Evaluation of the climate benefits of the use of Harvested Wood Products in the construction sector and assessment of	Bolscher, H., Schelhaas, M., Garcia Chavez, L., et al.	2021	(205)	Page 10: To take into account the benefits of temporary (biogenic) carbon storage in wood products and crediting them, the use of a simplified dynamic LCA approach is suggested, one that does not follow the carbon neutrality assumption. This method also allows to take into account the effect of lifetime extending practices. Page 243: The results seem to indicate that the benefit of growing the wooden products outweighs the onus of the emissions arising from manufacturing other building materials and from all endof-life activities. Varying assumptions on the lifetime of the buildings did not have a large impact on the outcomes. The difference between sawn-wood and CLT did have a great impact, calculations are based on CLT as this is currently the only way of constructing larger wooden buildings. So far, we have not included end-of-life alternatives for the carbon stored	Neutral	This study does not give specific arguments supporting or criticising temporary carbon storage in biobased materials, although the basic premise seems to be that usage of Wood Products in the EU Construction Sector should be stimulated. The study does recognize that none of the reviewed methodologies is perfect for quantification of benefits and that different methodologies can bring to significantly different results. As a general recommendation, a new methodology

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
Remuneration schemes				as this is scientific standard. However, we can imagine that in the future, with more standardized CLT construction elements and proof of their longer physical lifetime, end-of-life can become an issue that needs to be reconsidered.		should take into account the impact of both biogenic and fossil GHG fluxes. Also noteworthy is that according to this study the volumes of carbon saved are not enough to trigger, in themselves, a financial incentive in the form of tradable carbon credit (p254)
How can carbon be stored in the built environment? A review of potential options	Matti Kuittinen, Caya Zernicke, Simon Slabik & Annette Hafner	2021	(206)	In order to reach carbon neutrality, GHG emissions from all sectors of society need to be strongly reduced. This especially applies to the construction sector. For those emissions that remain hard to reduce, removals or compensations are required. Such approaches can also be found within the built environment, but have not yet been systematically utilized. This paper presents a review of possible carbon storage technologies based on literature and professional experience. The existing technologies for storing carbon can be divided into 13 approaches. Some are already in use, many possess the potential to be scaled up, while some presently seem to only be theoretical. We propose typologies for different approaches, estimate their net carbon storage impact and maturity, and suggest a ranking based on their applicability, impact, and maturity. Our findings suggest that there is an underutilized potential for systematically accumulating atmospheric carbon in the built environment.	Neutral	In this study a premise is that the EU forest sector can contribute to climate change mitigation, including by means of carbon storage. A precondition for this is sustainable forestry and parallel active reforestation. This study also rates the climate potential of biobased constructions materials (especially wood, bamboo and straw) as high, with the side note that the timing of uptake is before usage, and the timing of storage equals the use phase. Also, it should be ensured that increasing carbon stocks in the built environment would not cause collateral emissions or decreases of other carbon pools.
Biogenic carbon in buildings: a critical overview of LCA methods	Hoxha, E., et al.	2020	(207)	The increasing pressure to reduce greenhouse gas emissions from buildings has motivated specialists to develop low-carbon products incorporating bio-based materials. The impact of these materials is often evaluated through life-cycle assessment (LCA), but there is no clear consensus on how to model the biogenic carbon released or absorbed during their life-cycle. Results identified that land-use and land-use-change (LULUC) impacts and carbon-storage credits are not included in most existing methods. In addition, when limiting the system boundary to certain life-cycle stages, methods using the −1/+1 criterion can lead to net negative results for the global warming (GW) score, failing to provide accurate data to inform decision-making. Deviation between the results obtained from different methods was 16% at the building scale and between	Neutral	The main criticism of traditional LCA approaches is that they do not consider the impact of the timing of the carbon emissions and the influence of the rotation periods related to the biomass growth. This can be problematic when assessing the impact of bio-based products. Not all biobased products can be considered as carbon neutral, specifically, timber products

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
				35% and 200% at the component scale. Of all the methods studied, the dynamic approach of evaluating biogenic carbon uptake is the most robust and transparent.		have a longer rotation period due to slow forest growth periods, so they cannot be considered as carbon neutral, in a short time horizon. Conversely, fast-growing bio-based materials, such as straw and hemp, have a short rotation period and can provide an effective mitigation effect on GHG emissions by rapidly removing carbon from the atmosphere. To better capture the impact of time, dynamic approaches are advised.
Carbon economy Studies on support to research and innovation policy in the area of bio-based products and services	COWI , Directorate-General for Research and Innovation (European Commission) , Nova Institute , Utrecht University	2021	(208)	The main aim of the project was to map out the current pathways available for the transition towards a low carbon economy as well as the barriers that hinder this transition. Based on the conclusions and key findings from the WPs, the authors set the scene for the future of the bio-based sector with a particular focus on ten case studies of regions and cities across the EU (WP4), an evaluation of promising innovations and novel technologies for the realisation of such an economy and a sweeping regulatory analysis containing Q1 2020 updates (WP3) on EU directives and regulations that pertain to the low carbon economy. This attention to the local level as well as the broader policy sphere is supported by a scientific understanding of the low carbon economy (WP1), potential future scenarios towards 2050 (WP2) as well as clear dissemination of the findings across the entire study (WP5). In the frame of the study an animated educational video was produced. The final study report contains an executive summary followed by each Work Package in its entirety, which can also be treated as stand-alone reports in their own right. The biosphere has a carbon stock of 4,200 Gt C with the largest share in soil (up to 1m depth), closely followed by permafrost and wetlands and a rather small share stored in vegetation. Considering only carbon in living organisms, plants make up the by far largest share, followed by bacteria. Apart from the flows of biomass and fossil resources to the technosphere, net flows to and from the atmosphere are determined. Those are especially relevant because net flows of carbon from the technosphere to the atmosphere (9 to 11 Gt C / year) contribute to global warming, while net flows from the atmosphere to the biosphere or the hydrosphere (3 Gt C and 2 Gt C / year respectively) compensate the anthropogenic greenhouse gas emissions partly.	Neutral	A basic assumption in this study, is that while fossil carbon from the lithosphere is contributing to global warming, carbon from the biosphere is kept in a circular flow and not leading to an increase of carbon in the atmosphere (in form of CO2). There is, however, nothing mentioned about temporary carbon storage/sequestration in biosphere/biobased materials.

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
Brief on the role of the forest-based bioeconomy in mitigating climate change through carbon storage and material substitution	GRASSI Giacomo; FIORESE Giulia; PILLI Roberto; JONSSON Klas; BLUJDEA Viorel; KOROSUO Anu; VIZZARRI Matteo	2021	(209)	This brief is one out of a series of Knowledge Centre for Bioeconomy's briefs which intend to provide independent evidence for EU policy in this field. 1. Assessing the role of the forest-based bioeconomy in mitigating climate change requires a "system-perspective", considering all possible options: increasing carbon stocks ('net sink') in forest land and in Harvested Wood Products (HWPs), and using wood to substitute other materials or fossil fuels. 2. Reducing the harvest appears the easiest option to increase the net forest sink in the short to medium term (2030-2050). However, this option would have negative socio-economic impacts in the forest sector and would likely lead to a net forest sink saturation in the long term. 3. Increasing the harvest would make more wood available for carbon storage in HWPs and for material substitution. However, in the short to medium term, the potential additional benefits from HWPs and material substitution are unlikely to compensate for the reduction of the net forest sink associated with the increased harvest. 4. A further increase in the net annual forest increment, through forest management practices and new forest area, is necessary to reverse the current trend of declining sinks and thus align the contribution of the forest-based bioeconomy with the EU goal of climate neutrality by 2050. 5. Part of this extra increment could also increase the potential for carbon storage in HWPs and for material substitution. A shift towards greater use of wood products with longer service lives and substitution benefits can enhance their climate change mitigation benefit.6. A holistic assessment is essential to guide policies that ensure that the forest-based bioeconomy makes an effective and resilient contribution to climate change mitigation.	Neutral	This study also takes trade-offs into account between various climate change mitigation options. Overall, while a significant increase in the forest sink would be required to meet the EU climate objectives in the medium term (2050), both current and projected trends of its determinants (gross increment, natural mortality, fellings), as well as the country projections up to 2025 suggest a declining net forest sink in the short term. Reversing this trend would require an extraordinary and urgent increase in the net annual forest increment, mainly through forest management practices and new forest area. Part of this extra increment could also increase the potential for carbon storage in HWPs and for material substitution. A shift to wood products with a higher service life, e.g. from paper to construction timber, would slow down the outflow and help conserve or enhance the growth of the HWP pool while maintaining a stable harvest over time

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
Expanding Carbon Stocks in Existing Forests – A Methodological Approach for Cost Appraisal at the Enterprise Level	Knoke, Thomas & Weber, Michael	2006	(199)	The study presents a comprehensive methodology for the appraisal of C-stock expansion in existing forests as a forest management activity according to Art. 3.4 of the Kyoto Protocol. It allows for producer costs of carbon sequestration in forest enterprises to be derived. The methodology is based on a non-linear programming approach considering economic optimisation as well as ecological, social and sustainability needs through constraints and risk integration. While introducing further constraints on carbon stocks, the carbon stored in forest biomass was increased in periodic increments. However, while extending the carbon stocks, the ecological and social constraints as well as sustainability requirements are not to be violated. Costs were derived for every additional Mg (Megagrams) of C per ha sequestered in comparison to a baseline management. Two basic cases were considered: First, a permanent carbon sequestration was assumed. Secondly, a temporary storage of additional carbon over 10 years was supposed. The potential willingness of buyers of carbon certificates to pay for temporary carbon sequestration was derived by a financial consideration. We assumed that, for a buyer, the value of a temporary carbon sequestration certificate would be equivalent to the return on the savings because an investment in technical measures on reduction of carbon emissions can be postponed. Temporary carbon storage proved to be an interesting alternative when compared with permanent sequestration of carbon. Basically the costs of additional Mg C sequestered increased when carbon sequestration in periodic increments was enlarged. Given a market price of 11.42 Euro per Mg C for 10-year temporary carbon storage, the management of the forest could expand additional sequestration up to 6 Mg C per ha. Doing so, additional carbon sequestration generates an economic surplus as the costs of the last Mg C per ha would equal the market price.	Positive	This study researched scenario's in which temporary carbon storage in existing forests proved to be the economical choice, while sequestering additional carbon.
Towards a model for circular renovation of the existing building stock: a preliminary study on the potential for CO2 reduction of	F Pittau et al.	2019	(203)	In the context of strategies for mitigating the impacts of climate change within European cities, increasing attention is being paid worldwide to the use of urban green infrastructure which, in addition to the potential for improving the quality of the urban environment, allow significant amounts of CO2 to be removed from the air. However, considering the peculiarities of the dense European cities, most of the available surfaces in urban areas are the perimeter walls of buildings of considerable age that are in urgent need of measures to upgrade their energy performance. Based on this premise, this paper investigates the potential for CO2 storage resulting from the application of energy retrofit solutions using biogenic insulating materials. Starting from the analysis of the demand for insulation materials necessary for the energy requalification of the residential existing building stock in 28 European countries, following the renovation target fixed by EU, the research analyses, through the adoption of a dynamic LCA approach, the environmental benefits of bio-based materials compared to traditional solutions. The use of these materials, especially if they are	Positive for fast-growing bio-based materials, critical on timber.	This article makes a case for fast-growing bio-based materials, such as hemp and straw, due to their considerable potential of capturing and storing carbon when used as thermal insulation for renovating existing facades in Europe. Unlike forest products, they do not require long rotation periods, and the capacity for storing carbon increases when they are used as thick insulation for exterior walls due to the rapid CO2 uptake in the crop fields.

Title	Authors	Year of publication	Ref.	Abstract/conclusion	Position on temporary carbon storage	Key contribution to conclusion
bio-based insulation materials				fast-growing - as the study shows - offers several advantages in terms of climate change mitigation by reducing the energy needs and CO2 emissions of the existing building stock and increasing carbon storage capacity within cities. The results of this study are intended to provide a robust database on which to build a model of circular building renovation that takes into account the environmental long-term effects of measures for increasing energy efficiency of buildings.		Contrarily, timber-based construction always contributes to increase the emissions from renovation in a short and mid-term prospective, and the carbon capture and storage capacity of wood, if only timber is used in the structure, seems cannot be proposed as a valid strategy in Europe to contribute achieving the Paris Agreement targets.

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 (198). 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 (202).

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. According to Kirschbaum et al. (197) storing carbon in biosphere sinks can indeed reduce atmospheric GHG concentrations in the short term. A time horizon of 20 years is used for the definition of "temporary" in this context. However, this would also lower the concentration gradient between the atmosphere and naturally occurring potential carbon reservoirs. This in turn, will negatively impact the potential for CO_2 removal from the atmosphere as a whole. In other words: trade-offs cannot be overcome and the ultimate impact of the temporary carbon storage on climate change will be negative. Kirschbaum comes to the conclusion that there is almost no climate mitigation potential for carbon storage less than 50 years.

In order to have any benefits from temporary carbon storage in timber, carbon neutrality through sustainable forestry and parallel active reforestation are unequivocal prerequisites (206), 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 (207)(203). 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. A shift to wooden products with a higher service life than currently is the case would be beneficial, as this would slow down the reduction of the net forest sink associated with increased harvest, as well as conserving or even enhancing the growth of the harvested wood products (HWP) pool (209).

11.3 Conclusions

The main conclusions from the literature review are:

- Both short- and long-term climate impacts and change mitigation potentials should be considered (202).
- The choice of time horizon in quantification of mitigation benefits may be arbitrary, but should nevertheless be made explicit, and, if possible, be standardized for comparison purposes. This also goes for the overall approach to quantify temporary carbon storage benefits.
- For timber to have a positive impact on climate change mitigation, sustainable forestry and parallel active reforestation is a precondition (206).
- Biobased products with short rotation periods related to biomass growth may be better suited for temporary carbon storage if a similar or longer life span of the resulting products is realistic (207).

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12 Mitigation potential of temporary carbon storage in HWP

12.1 Introduction

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 (211) and the new European Bauhaus initiative (212).

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

12.2 Global GHG emissions and reduction efforts

Global net anthropogenic GHG emissions amounted to 59±6.6 Gton CO_2eq in 2019, about 12% (6.5 Gt CO_2-eq) higher than in 2010 and 54% (21 Gt CO_2-eq) higher than in 1990. Historical cumulative net CO_2 emissions from 1850 to 2019 were 2400±240 Gton CO_2eq (213).

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, and as 1150 Gton CO_2eq for a for limiting warming to 2°C (213).

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, taking into account the effect of other anthropogenic climate forcers. 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 (213).

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.

12.2.1 Contribution by buildings

The recent IPCC draft assessment report (213) indicates that buildings have the potential to contribute more than 20% to the global effort, see Figure 12.2.

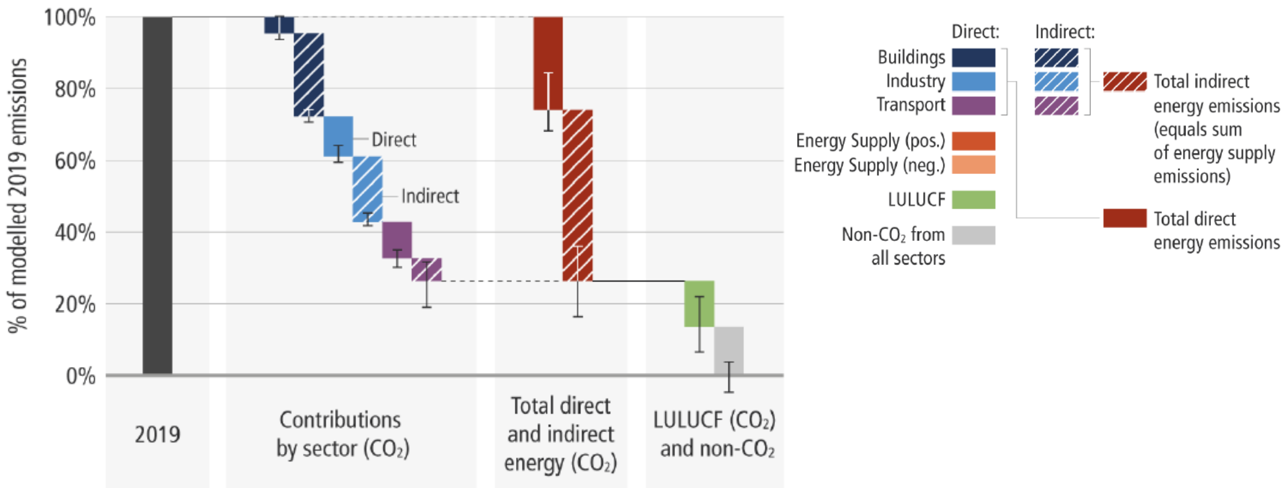

Figure 12.1

Relative contribution of different sectors and LULUCF to global anthropogenic GHG emissions. Source: IPCC (213).

Specifically, global GHG emissions associated with buildings amounted to 12 Gton CO_2eq in 2019, equivalent to 21% of global GHG emissions. Of this, 57% (6.8 Gton CO_2eq) were indirect emissions from offsite generation of electricity and heat, 24% (2.9 Gton CO_2eq) direct emissions produced onsite (e.g. heating and cooking) and 18% (2.2 Gton CO_2eq) were embodied emissions from the production of construction materials used in buildings (213). This means that the absolute maximum emission reduction potential from construction materials in buildings can contribute no more than 6.5% to the total global effort up to 2050 (= 2.2 Gton/yr x 29 yr/981 Gton). This is assuming that *all* GHG emissions from construction materials were eliminated immediately (2.2 Gton CO_2eq/yr), which is not realistic.

12.3 Size of the net carbon sink for HWP in construction

12.3.1 Global potential

The use of wood products refers to the fate of harvested wood for material uses and includes two distinctly different components affecting the carbon cycle, including carbon storage in wood products and material substitution. When harvested wood is used for the manufacture of wood products, carbon remains stored in these products depending on their end use and lifetime.

Since the publication of the IPCC's Special Report on Climate Change and Land (214) 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 (2015) estimated that carbon storage in wood products represented a net carbon stock increase of 0.34 Gton CO_2eq/yr globally in 2015 and which could provide an average mitigation potential (by increasing the HWP pool) of 0.37 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 (213) 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. The total future mitigation potential will depend on the forest system considered, the type of wood products that are produced and substituted and the assumed production technologies and conversion efficiencies of these products.

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. Xi et al. (216) found that carbonation of cement materials over their life cycle represents a large and growing net sink of CO_2, increasing from 0.10 Gton C/yr (= 0.33 Gton CO_2/yr) in 1998 to 0.25 Gton C/yr (= 0.82 Gton CO_2/yr) in 2013. These reversal sinks have so far not been considered in substitution scenario's, but can have significant impact. Further research, outside the scope of this study, is required to properly account for carbonation of cementitious construction products, but this suggests that the potential sink of carbonation is up to par with (or higher than) the global potential sink of wood products.

12.3.2 Potential HWP sink of the EU

From previous assessments within the scope of this study (see chapters 5 and 6), it became clear that an exact balance of the amount of timber harvested/consumed within the EU that is used as HWP in construction is not available. However, statistics on the net potential carbon sink size of all HWP over the last 30 years are available (217), and shown in Figure 12.2.

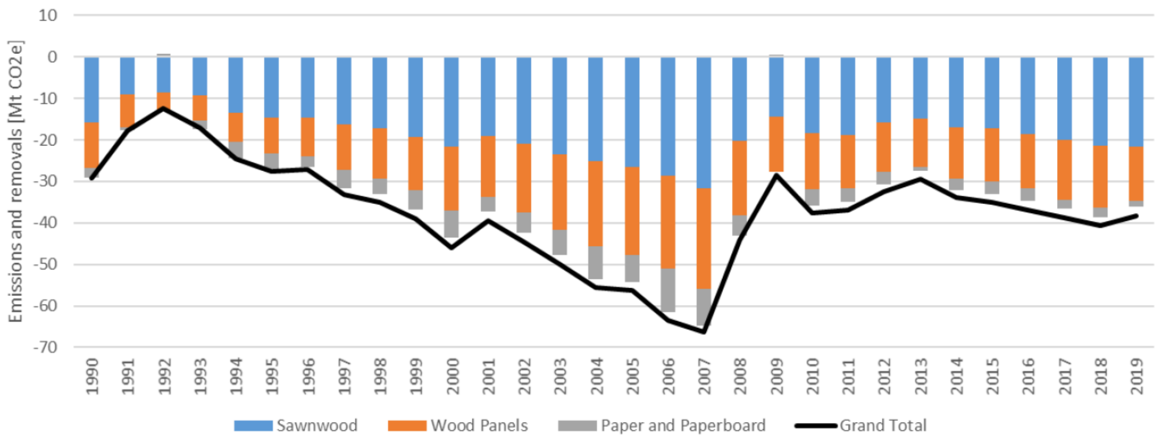

Figure 12.2
Net GHG emissions for HWP for the EU-27 since 1990 (in Mton CO_2eq). Source: EC (217).

On average, net GHG emissions for HWP in Europe ranges between -12 and -66 Mt CO_2eq with a decrease in the first years, a steady increase until 2007, followed by a sudden drop and since then relatively stable. HWP categories sawn wood (average: -18 Mt CO_2eq) and wood panels (-13 Mt CO_2eq) contribute highest, amounting to a total net sink for HWP of approximately 31 Mton CO_2eq per year.

A different approach to assess the size of the net carbon sink for HWP is to look at the carbon stock change in the HWP pool reported in the national GHG inventories (218) which is based on the balance of the annual inflow of harvested and processed domestic wood and the outflow from the pool through oxidation of the carbon in wood products that reach their end-of-life. The size of the net carbon sink for HWP was reported to be approximately 40 Mton CO_2eq/year (224).

12.4 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 (see Annex V).

Compared to the reference levels of 2005, the total GHG emission reduction target for the EU-27 up to 2030 can be calculated from Annex V. This amounts to 5.2 Gton CO_2eq. In order to arrive at a total GHG emission reduction target for the year 2050, for the period between 2030 and 2050, a linear decrease in annual emission allocation is assumed, as shown in Figure 12.3. The total reduction percentage in 2050 is set at 95% (compared to the level in 2005).

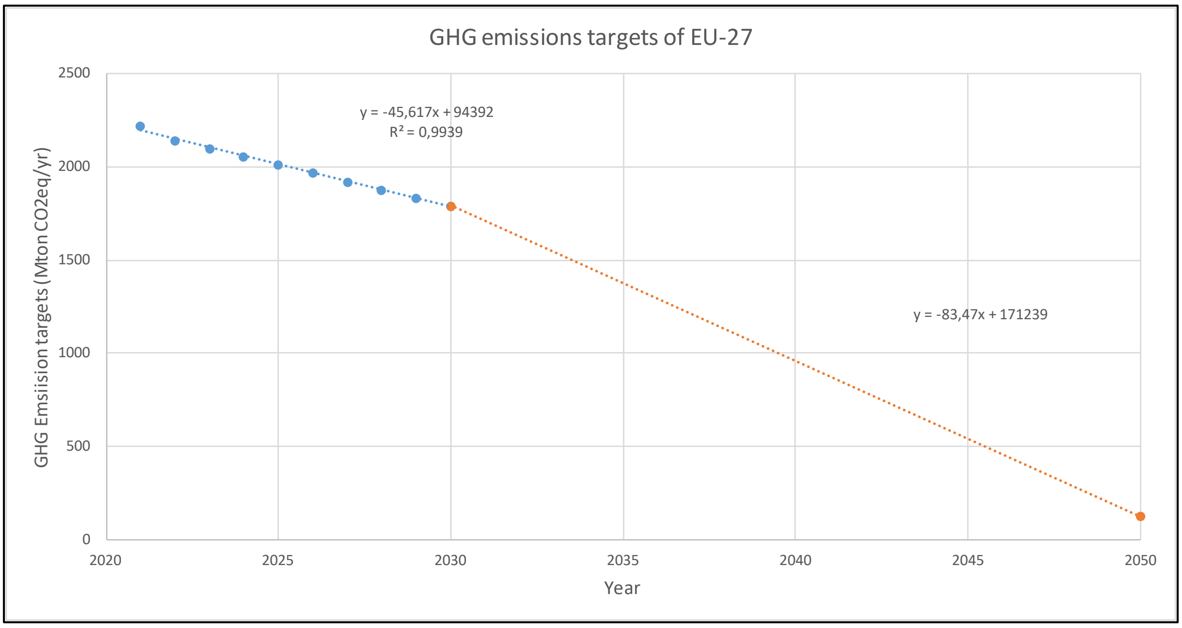

Figure 12.3
GHG emission targets for the EU-27 in the time period 2021-2050.

By using this approach in combination with emission levels in 2005, 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.

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

In the previous sections, 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.

12.5.1 Relative contribution to EU-27 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 12.3.2). 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.

12.5.2 Relative contribution to the global emission reduction effort

When looking at the remaining global GHG budget (within the 1,5 °C 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 (assuming after 2050 the global GHG emission is allowed to stay at 10 Gton

CO_2eq/yr. 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.

12.5.3 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 (219). A near linear relationship between the cumulative CO_2 emissions and global warming for the five GHG scenarios until the year 2050 was reported, as shown in Figure 12.4

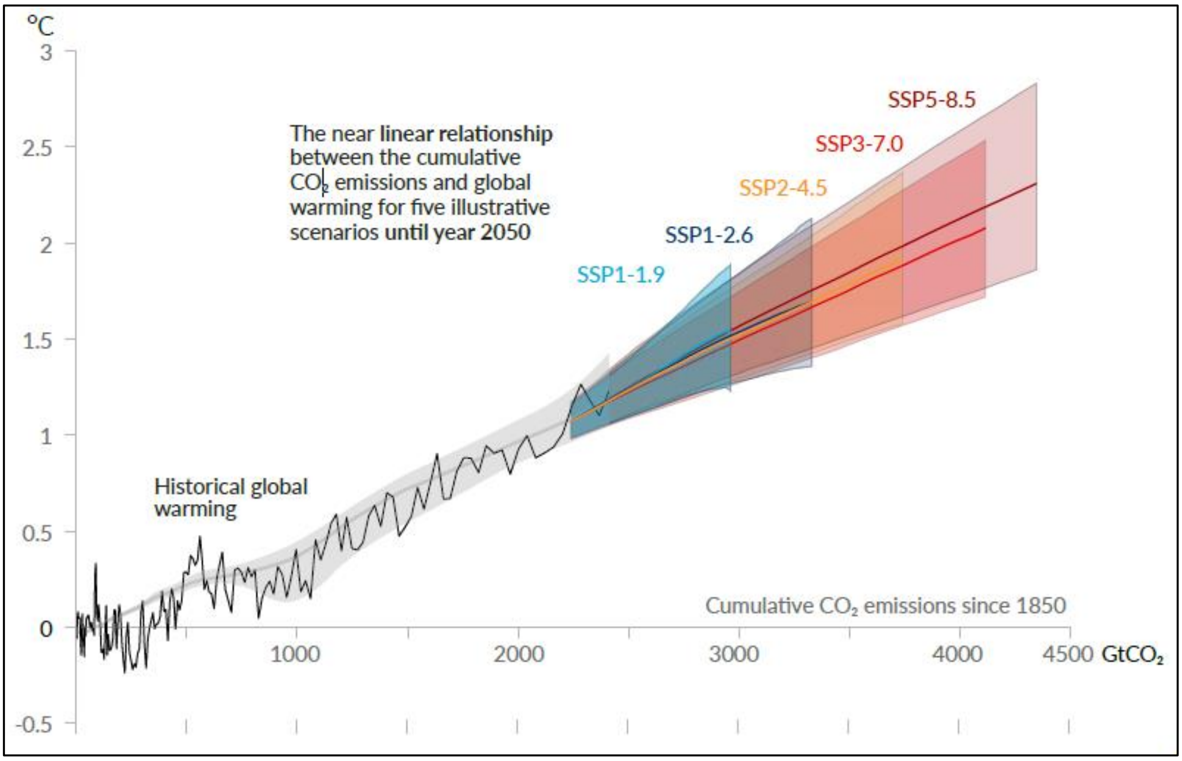

Figure 12.4
Near-linear relationship between cumulative CO_2 emissions and the increase in global surface temperature. Reprinted from: IPCC (219).

The background data for these scenarios were downloaded and combined to calculate their linear regression. The subsequent regression plot is shown in Figure 12.5.

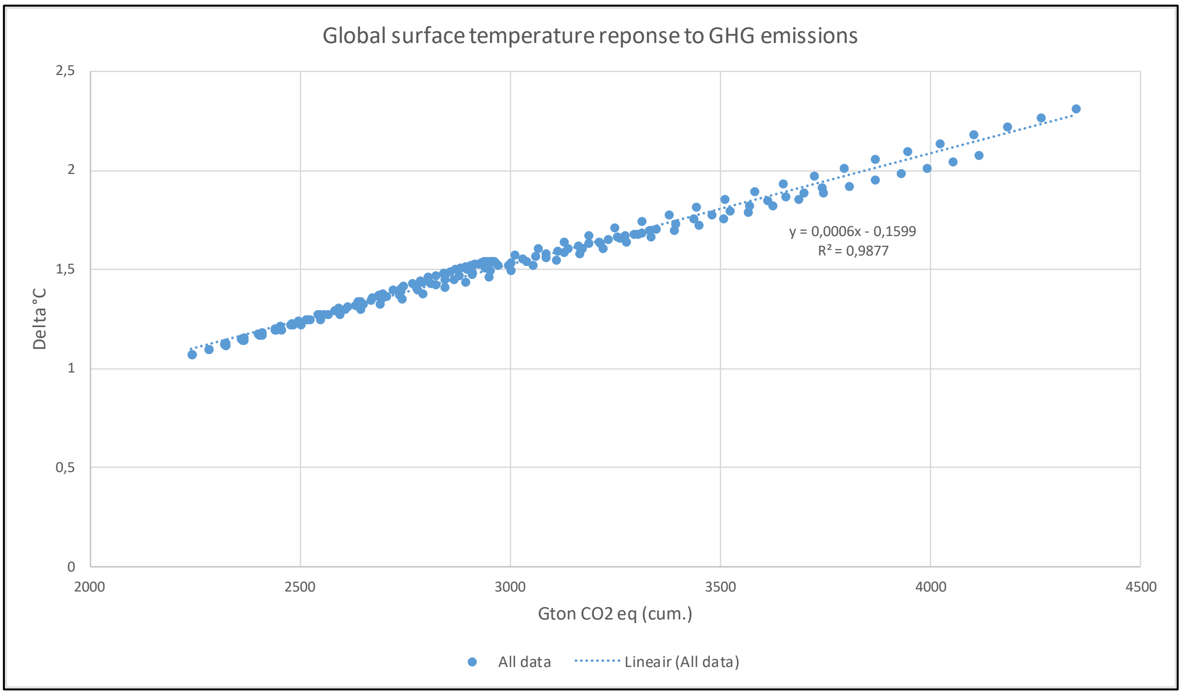

Figure 12.5
Regression plot of global surface temperature change as a function of cumulative GHG emissions.

The slope of the regression line is used to calculate a derivative of the relative contribution of temporary carbon storage in HWP to mitigation of climate change expressed as °C 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 °C 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 °C, whereas the current yearly potential net carbon sink of the HWP pool in the EU-27 would amount to no more than 0.002 °C.

These numbers for mitigation potential do not take into account (consequential) substitution effects, where GHG-intensive materials are replaced by HWP. These material substitution benefits, i.e. the GHG emissions avoided by using HWP instead of other fossil-based materials, are assessed by multiplying the amount of wood used to substitute other materials (on top of the reference case) by a substitution factor (SF) [7].

It should be noted that the substitution factor has a large impact on final results and is characterised by a high level of uncertainty. In literature, SF values ranging from 1.1 to 2.1 t C / t C

7 Assuming no decarbonisation in the underlying period takes place in the production systems of currently-fossil-based materials.

are reported (220)(221)(222)(223). This means that for each ton of carbon in HWP, there is an average reduction in emissions to the atmosphere of between 1.1 and 2.1 tons of carbon. When applying these SF values (without any further scrutiny, see also section 8.7.1), the calculated potential reduction in global surface temperature would roughly double to triple.

12.6 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, 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.

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Annex I

Production capacity of laminated timber

Production capacity of gluelaminated timber in Europe:

Company	Yearly production capacity (m3)	Country
Hasslacher + Nordlam	400.000	Austria Germany
Mayr-Melnhof Holz	320.000	Germany Austria
Binderholz	265.000	Austria
Mosser	180.000	Austria
Schneider	160.000	Germany
Versowood	135.000	Finland
Bullinger	125.000	Germany
Pfeifer Holz	120.000	Austria
Weinberger Holz	115.000	Austria
Eugen Decker	100.000	Germany
Theurl Austrian Premium Timber	100.000	Austria
Johann Pabst Holzindustrie	95.000	Austria
Rubner	85.000	Austria Italy
Wiehag	85.000	Austria
Kirnbauer	80.000	Austria
Moelven	80.000	Sweden Norway
Ziegler Holztechnik	75.000	Germany
Ladenburger	75.000	Germany
Ante-Holz	70.000	Germany
Handlos	65.000	Austria
Setra	55.000	Sweden
Martinsons (Holmen)	50.000	Sweden
ASTA Holzwerk	50.000	Germany
Derix	50.000	Germany

Production capacity of cross laminated timber in Europe

Company	Yearly production capacity (m3)	Country
Binderholz	220.000	Austria Germany
Stora Enso	170.000	Finland
KLH Massivholz	130.000	Austria
Mayr-Melnhof Holz	65.000	Austria
Hasslacher + Nordlam	60.000	Austria Germany
Splitkon	50.000	Norway
Schilliger Holz	40.000	Austria
Theurl Austrian Premium Timber	40.000	Austria
Derix	30.000	Germany
Artuso Legnami	30.000	Italy
Pfeiffer Group	30.000	Germany
Züblin Timber	30.000	Germany Italy
Lignotrend	25.000	Germany
Best wood Schneider	25.000	Germany
Eugen Decker	25.000	Germany

Annex II

Additional information on particle board production

Particle board production requires 'clean waste wood' or 'chipboard grade' waste wood. Though there is no officially adopted definition of recyclable waste wood, in general the following specifications for supplied wood seem to apply:

- A maximum of 5-10% of wood from board products (B-wood).
- Solid waste wood from the following sources:
  - residues from joinery, furniture, wood products manufacture (A-wood);
  - packaging waste, pallets and crates from commercial businesses (A-wood);
  - sorted construction and demolition waste (such as lumber, panel shapes, doors, cabinets: B-wood).
- A limited contamination with non-wood materials, such as metals, glass, stones, gypsum, etc. These contaminants are removed in the particleboard production process.
- Concentration of contaminants should be lower than the limits shown in Table II.1 below.

Table II.1 Concentration limits for contaminants in waste wood destined for particleboard production

Elements/Compounds		Limit values (g/kg)
Cadmium	(Cd)	0.075
Copper	(Cu)	0.04
Fluorine	(F)	0.1
Pentachlorophenol	(PCP)	0.005
Cadmium	(Cd)	0.075
Copper	(Cu)	0.04
Arsenic	(As)	0.025
Chromium	(Cr)	0.06
Lead	(Pb)	0.09
Chlorine	(Cl)	1
Creosote	(Benzo(a)pyrene)	0.0005
Arsenic	(As)	0.025
Chromium	(Cr)	0.06
Lead	(Pb)	0.09

Part of the utilised raw materials are released as residues, e.g. as chips of undesired sizes and sand down dust. When based on sawmill chips, approximately 10-15% of the utilised wood is 'lost' a by-product. For waste wood, this percentage may be higher (no data found).

The residues are incinerated in CHP boilers for generation of steam required for drying the particleboard raw materials. Fuel consumption for drying and other processes in particleboard production amounts to 3.0–3.5 GJ/tonne particleboard.

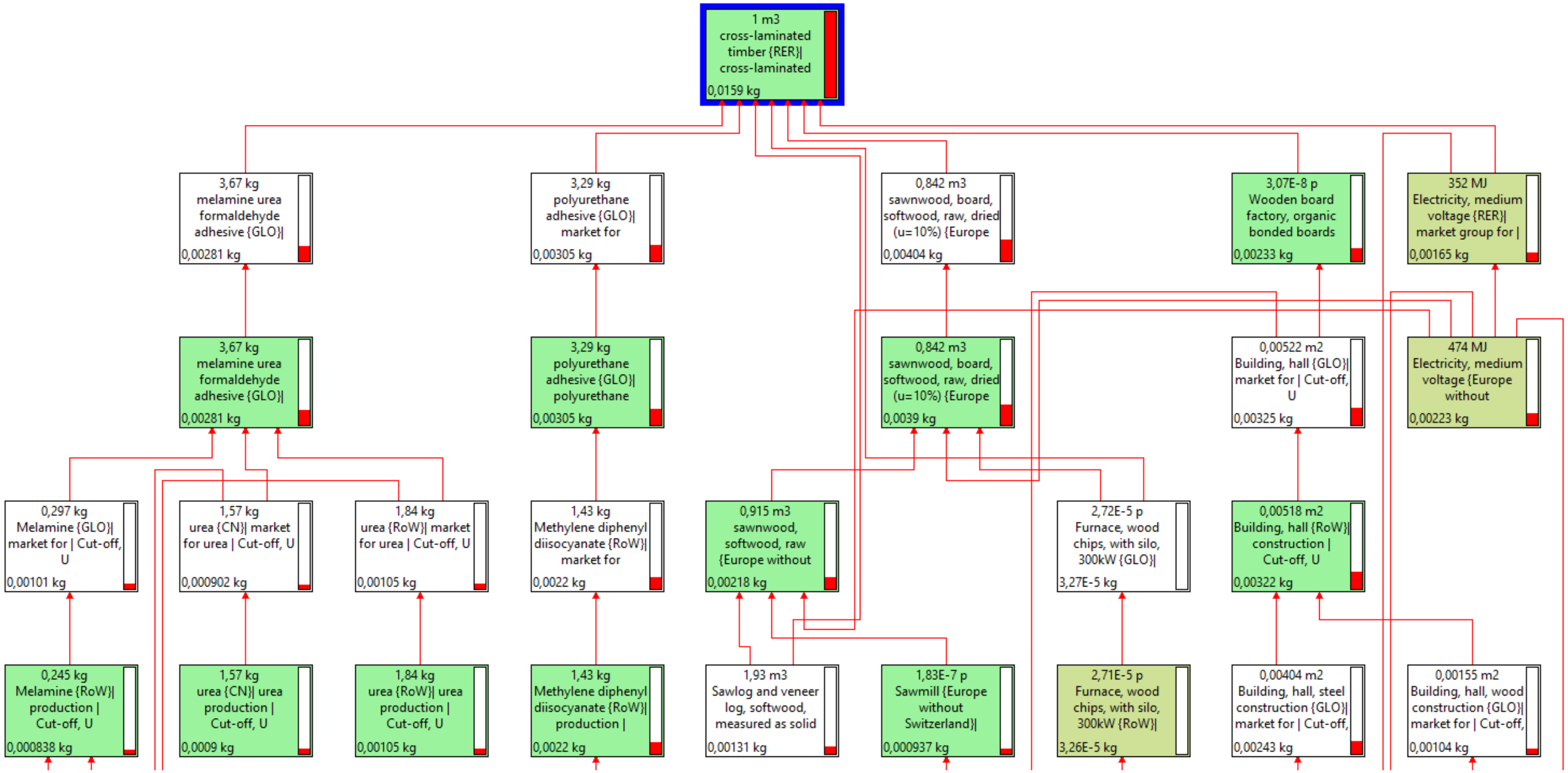
Because of its lower moisture content – compared to sawmill by-products and round wood - waste wood-processing requires less energy.

In efficient production processes in which high shares of waste wood are applied as raw material, a surplus of fuel may be available, allowing for operating a CHP plant, supplying part of the produced power to the grid.

An example of such a plant is probably the A&S Energie CHP plant located at the site of the SPANO particleboard plant in Oostrozebeke. The particleboard plant produces approximately 400,000 tonnes of particleboard annually and redirects recovered wood unsuitable for recycling and residues from particleboard production to a power plant which is operated by a daughter company. The bio-energy CHP boiler consumes 180,000 tonnes of biomass per year, which is comparable to 30% of the aggregated amount of produced particleboard and wood fuel. This could indicate that the CHP plant processes more than only by-products of particleboard production. The CHP plant supplies steam to the Spano particleboard plant.

Annex III

Network example of background processes for 1 m^3 of CLT production



Cut out showing part of the extensive background process network for the production of 1 m^3 CLT. This specific example shows that the Ecoinvent process for 1 m^3 CLT is inclusive of the adhesives and resins used in the production process, and therefore includes its respective GHG emissions in the total process.

Annex IV

Overview of analysed EPDs

= Selected for in depth analysis

EPD program	PCR available	product type	productname	functional unit	modules declared	RSL (years)	EPD owner	date	standard version	Taal EPD	Cut off	Allocation	Losses	Mass balance wood	EOL scenario	CO2 emissions	Possible omissions	Biogene CO2 flow	Conform PCR?	Database	Used 16449
NMD (alleen cat. 1 of 2)												Search setup: PCR 'Wood', based on A2 version									
IBU	Wood based panels	wood based panels	**PerfectSense Lacquered Boards**	1 m² EGGER PerfectSense Lacquered Board (13.2 kg/m²	A1-A3,C1-C4,D	10-40 years	Egger	29-7-2021	A2	Engels	Search published EPDs (epd-online.com)										
IBU	Solid wood products	Solid wood products	**Egger timber / Schnittholz technisch getrocknet, sägerau und gehobelt**	1 m³ technisch getrocknetes, sägeraues und gehobeltes Schnittholz (503 kg/m³) mit einer Feuchte von 15 %	A1-A3,C1-C4,D	im Durchschnitt 50 Jahre	Egger	10-5-2021	A2	Duits/Engels											
IBU	Wood based panels, t EN 13986:2004+A1:2015, Wood-based panels for use in construction – Characteristics	Wood based panels	**Medium Density Fibreboards EGGER MDF**	1 m³ mitteldichte Faserplatte MDF (736 k	A1-A3,C1-C4,D	10-40 Jahren	Egger	10-5-2021	A2	Duits/Engels	<1% of impact. Total cut off < 5% of mass & energy input	. **Allocation within the forestry chain is based on the publication of Hasch 2002 and its update by Rüter & Albrecht 2007.** A price allocation according to Rüter & Diederichs 2012 a for sawing by-products of roundwood. The thermal and electrical energy generated in the cogeneration plants is allocated according to exergy.		Wood chips, wood type mainly spruce and pine, 81 % Water 5-7 % UMF glue (melamine-urea-formaldehyde resin) approx. 12% Ammonium phosphate (fire retardant, only in Flammex product variant) Paraffin wax emulsion <1 %	100% incineration with energy recovery (biomass power plant).	som CO2eq total: -150kg per FU.	Expenses for machinery and infrastructure were not considered	A1A3:.- 1090 kg C2: -3,89E-3 kg C3: + 1100 kg D: -1,61 kg	Yes, the allocation methods should be checked.	Gabi	No
IBU	Wood based panels	Wood based panels	**Eurospan Raw Chipboard / Eurospan Rohs**	1 m³ Rohspanplatte (655 kg/m³) mit eine	A1-A3,C1-C4,D	10-40 Jahren	EGGER	10-5-2021	A2	Duits/Engels											
IBU	Wood based panels	Wood based panels	**EGGER Eurodekor - Melamine Faced Chipb**	1 m² EGGER Eurodekor beschichtete S	A1-A3,C1-C4,D	10-40 Jahren	EGGER	10-5-2021	A2	Duits/Engels											
IBU	Wood based panels	Wood based panels	**EGGER Eurodekor - Laminated MDF board**	1 m² EGGER Eurodekor beschichtete M	A1-A3,C1-C4,D	10-40 Jahren	EGGER	10-5-2021	A2	Duits/Engels											
IBU	Wood based panels	Wood based panels	**EGGER DHF**	1 m³ EGGER DHF-Platte mit einer durch	A1-A3,C1-C4,D	50	EGGER	19-4-2021	A2	Duits/Engels											
IBU	Wood cement - Mineral-bonded wooden composites	Wood based panels	**Duripanel A2**	1 m² Duripanel A2 with thickness 19mm.	A1-A3,A4,A5,B1,B2,B6,B7,C1-C4,D	>50	Etex Germany Exteriors	1-4-2021	A2	Engels											
IBU	Wood cement - Mineral-bonded wooden composites	Wood based panels	**Duripanel B1**	1m² Duripanel B1 with thickness 18mm.	A1-A3,A4,A5,B1,B2,B6,B7,C1-C4,D	>50	Etex Germany Exteriors	1-4-2021	A2	Engels											
IBU	Solid wood products	Structural timber products	**Structural finger jointed solid timber & GLT**	1 m³ Konstruktionsvollholz mit einer durc	A1-A3,C1-C4,D	>100	HASSLACHER Holding	3-8-2021	A2	Duits/Engels											
IBU	Solid wood products	Structural timber products	**Glued laminated timber, glued solid timber,**	1 m³ Brettschichtholz mit einer durchsch	A1-A3,C1-C4,D	>100	HASSLACHER Holding	3-8-2021	A2	Duits/Engels	<1% contribution cut off. <5% of total material/water/energy flows	**The allocation in the upstream supply chain of wooden products is based on the publication by Hasch 2002 and its update by Rüter & Albrecht 2007.** Co-products are allocated based on their market price in accordance with the recommendations of EN 16485 Thermal energy used is considered burden free (from a waste incineration plant)		- Softwood, predominantly spruce, approx. 88.5-89.5 % - Water approx. 9-10 % - MUF adhesives approx. 1.5 % - PUR adhesives < 0.1 % - EPI adhesives < 0.1 % - PRF adhesives < 0.1 %	100% incineration with energy recovery. Landfill is forbidden for wood products	Sum of GWP total: **-263,58** kg CO2	No information is presented on the forestry certificate. It is not sure that all forestry is done sustainably and that the materials enter as '- '.	A1A3: -753 kg C2: -1,67E-3 kg C3: +750 kg. D: -1,42 kg		Gabi	No
IBU	Solid wood products	Structural timber products	**HASSLACHER CROSS LAMINATED TIMBER**	1 m³ Brettsperrholz HASSLACHER CRC	A1-A3,C1-C4,D	>100	HASSLACHER Holding GmbH	3-8-2021	A2	Duits/ Engels	<1% contribution cut off. <5% of total material/water/energy flows	The allocation in the upstream supply chain of wooden products is based on the publication by Hasch 2002 and its update by Rüter & Albrecht 2007. Co-product allocation on market price (according to EN 16485)		The averaged proportions of ingredients per m³ of HASSLACHER CROSS LAMINATED TIMBER for the environmental product declaration are: - Softwood, mainly spruce, approx. 88 - 90 %. - Water approx. 9 - 10 % - MUF adhesives approx. 1 - 2 %	100% incineration with energy recovery.	Sum of GWP total: **-316** kg CO2	**Biogene CO2-eq is negative, how?**	A1A3: -754 kg C2: -1,67E-3 kg C3: **750** kg **(??)** D-1,42 kg. Unclear why A1A3 storage is larger than C3 emission.		GAbi	No
IBU	Solid wood products	Structural timber products	**Admonter Massivholzmehrschichtprodukte**	1 m² Admonter Massivholzmehrschichtp	A1-A3,C1-C4,D	40	Admonter Holzindustrie	23-7-2021	A2	Duits											
MRPI	SBK; Milieuprestaties Gebouwen en GWW Werken, version 2.0, November 2014	Wood based panels	**Hakwood Duoplank® in European Oak or E**	1 m2 (10.76 s.f.) Flooring, applied in an office for a period of 50 years, per 1 m2	A1-A3,A4,A5,,B2,B3,C2,C4,D	50	Hakwood	16-7-2019	EN15804	Engels	No Cut off	Landfill & incineration according to Bepalingsmethode	Unclear	Unclear, not separately declared	Default values NMD	**A1=6,87kg** D= -5,9kg	-	-	Wood products are FSC, yet appear to enter A1 as positive CO2. The products are available FSC on request. This means that not all products are certified and therefore material cannot enter the system with a negative CO2eq value. This is **in line with EN16485**		No
IBU	Wood cement - Mineral-bonded wooden composites, 01.2019	Wood composites	**Natural Wood, unpainted**	Acoustic panel "Natural Wood" - 1m2 , 2	A1-A3,A4,A5,B1,C1,C2,C4,D	50-75	Troldtekt A/S	27.04.2021	EN 15804	Engels	https://www.eco-platform.org/epd-data.html										
IBU	Wood cement - Mineral-bonded wooden composites, 01.2020	Wood composites	**Acoustic panels - unpainted Troldtekt A2 N**	Acoustic panel "A2 Natural Wood" - 1m2	A1-A3,A4,A5,B1,C1,C2,C4,D	50	Troldtekt A/S	27.04.2021	EN 15804	Engels											
IBU	Holzwerkstoffe, DIN EN 13171:2015-04 Wärmedämmstoffe für Gebäude - Werkmäßig hergestellte Produkte aus Holzfasern (WF) - Spezifikation; Deutsche Fassung EN 13171:2012+A1:2015 EN16485	wood fibre insulation boards	**Holzfaserdämmplatten**	Die zugrundeliegende deklarierte Einheit ist 1 m³ Holzfaserdämmplatte mit einer nach Produktionsmengen (m³/Jahr) gewichteten mittleren Dichte von 167 kg/m³.	A1-A3, A5, C3, D	40	GUTEX Holzfaserplatte	09.10.2020	EN 15804	Duits	No cut off Biogene CO2 is considered.	Based on mass. There is a closed loop (pre-consumer) waste recycling		94,5-96,5% wood 1m3=167kg 8% mosture uppon delivery.	incineration with: Energy recovery 100% CO2 is considered in line with EN16485	A1-A3: -198,4kg A5: 21,76 kg C3: 270kg D: -184,5 kg **Sum: -91kg**	At EOL a 100% energy recovery is assumed. Sum of CO2 is negative	-			No
Eco-platform / EPD-Norway DIGI	NPCR015 rev1 wood and wood-based products for use in construction (08/2013).	Wood based panels	**Brannpanel Optimum - Brannimpregnert Th**	1 m2 varmebehandlet, brannimpregnert og overflatebehandlet kledning av furu til utvendig bruk, fra vugge-til-grav med en referanselevetid på 60 år	A1-A3,A4,A5,B2,B3,C1,C2,C3,C4,D	60	Woodify AS	12.09.2019	d EN 15804	Noors											
Eco-platform / EPD-Norway DIGI	NPCR015 rev1 wood and wood-based products for use in construction (08/2013).	Wood based panels	**Woodify Optimum - Thermowood av furu el**	Produksjon av 1 m2 varmebehandlet og	A1-A3,A4,A5,B2,B3,C1,C2,C3,C4,D	60	Woodify AS	12.09.2019	d EN 15804	Noors											
Eco-platform / EPD-Norway DIGI	NPCR015 rev1 wood and wood-based products for use in construction (08/2013).	Wood based panels	**Woodify Natur - Thermowood av furu eller**	Produksjon av 1 m2 varmebehandlet kle	A1-A3,A4,A5,B2,B3,C1,C2,C3,C4,D	60	Woodify AS	12.09.2019	d EN 15804	Noors											
Eco-platform / EPD-Norway DIGI	NPCR015 rev1 wood and wood-based products for use in construction (08/2013).	Wood based panels	**Produksjon av 1 m2 varmebehandlet kledni**	Produksjon av 1 m2 varmebehandlet og	A1-A3,A4,A5,B2,B3,C1,C2,C3,C4,D	60	Woodify AS	12.09.2019	d EN 15804	Noors											
Eco-platform / EPD-Norway DIGI	NPCR015 rev1 wood and wood-based products for use in construction (08/2013)., EN16485, EN 16449	Wood based panels	**Brannpanel Natur - Thermowood, Brannpan**	1 m2 varmebehandlet og brannimpregne	A1-A3,A4,A5,B2,B3,C1,C2,C3,C4,D	60	Woodify AS	12.09.2019	d EN 15804+A	Noors	<1% contribution cutt of. <5% effect on all impact categories	Economic allocation.	7,81/15,1= 52% in A1A3	8,25kg Pine wood 1,49kg water in wood 8,8% brannimpregnert middel	mixed waste incineration. Waste code 170201 (EAL). 9kg for energy recovery	Sum: 10,7kg CO2eq Some credit at module D '-0,785 kg CO2'.		A1A3 .-15,1kg CO2 biogene A1A3 + 7,81kg CO2 biogene (this must be losses) IOBC A1A3 result: -7,32kg CO2 bio A5: . C3 GWP-BC: +15,1 C3 GWP-IOBC: +1,49 calculated according to EN 16449:2014	**Need to check 16449:2014**		Yes
Eco-platform / EPD-Norway DIGI	CEN Standard EN 15804 tjener som kjerne PCR. NPCR015 rev1 wood and wood-based products for use in construction (08/2013	Wood based panels	**Utvendig kledning av Superwood**	1 m³ utvendig kledning av Superwood, pı	A1-A3,A4,A5,B2,C1,C2,C3,C4,D	60	Superwood AS	1-10-2018	EN 15804	Noors											
Eco-platform / Environdec	2012:01-Sub-PCR-E Wood and wood-based products for use in construction (EN 16485)	Construction products / Floor coverings	Lightwood and MaxWood				Golvabia AB	17-12-2018	EN 15804		PDF not available										
Eco-platform / Environdec							Norbord Europe Ltd														

EPD program	PCR available	product type	productname	functional unit	modules declared	RSL (years)	EPD owner	date	standard version	Taal EPD	Cut off	Allocation	Losses	Mass balance wood	EOL scenario	CO2 emissions	Possible omissions	Biogene CO2 flow	Conform PCR?	Database	Used 16449
Eco-platform / Environdec							Svenska Fönster AB														
Eco-platform / Environdec							Daloc AB														
Environdec	006, Wood and wood-based products for use in construction (EN 16485)	Planed wood products	**Swedish sawn and planed wood product**	1m3 Swedish planed wood product of spruce (59%) and pine (41%) with an average moisture ratio of 16 %	A1-A3, C1-C4, D	-	Swedish Wood	15-6-2021	EN 15804:A2	Engels	-	According to EN 15804, economic allocations.	-	spruce (59%) and pine (41%). 489 kg/m3	incineration With recycling module D can become -144kg)	A1-A3: -743kg C1: 0,245kg C2: 6,67kg C3: 774kg D: -116 kg Sum: -78kg		Sustainably managed forest wood from Sweden. A1A3: -773kg C3: +773kg	yes	Ecoinvent 3.6	No
Environdec	: Construction Products, PCR 2019:14	Wooden panels and floors	Wooden panels and floors	1 m2 of panel/floor installed at customer.	A1-A5, C1-C4, D		Norrlands trä AB	jan-21	EN 15804:A2	Engels											
Environdec	EN 16485:2014, PCR 2019:14	Wooden panels and floors	**ThermoWood®**	1 m³ of Thermowood® with a moisture content of 6%	A1-A3, C1-C4, D	>100 years	Stora Enso	10-2-2021	EN 15804:A2	Engels	1%. This rule is based on the assumption that the input flows do not have a major impact on the environmental impacts as a whole.	according to EN15804. Physical, economic and energy allocations have been used.	-	Half of the dry mass of wood is carbon. Each kg of stored biogenic carbon is equal to ~3.67 kg of CO2, which is effectively removed from the atmosphere. In case of sawn timber the biogenic carbon content is -744 kg CO2 eq./m³.	Three scenario's, reycling, incineration, landfilling	GWP total: A1A3: -666kg (if recyling) C1: -,0003 C2: 1,82kg C3: 749kg C4: 0 D: -797kg Incineration C1: -,0003 C2: 1,82kg C3: 763kg C4: 0 D: --379kg Landfill C3: 0 C4 **1790 (why so high?** D: -3,54kg (if landfill)	**The 'D' benefits for recycling are larger than A1-A3.** Module D incineration saves nat. Gas. D landfill the methane uptake from landfill partly substitutes natural gas in heat production **(??)**	1 kg biogenic carbon is equivalent to 44/12 kg of CO2, Calculation based on EN 16449, FSC wood Recyling A1A3- 744kg **C3: 744kg. (?)** **D: -745kg if recycling(?)** **Incineration** **C3: 744** D: -0,03 (incineration) Landfill C3: 0 C4: 1780kg D: -0,0006 (land fill)		Ecoinvent 3.5	Yes
Environdec	EN 16485:2014, Sub-PCR-E to PCR 2012:01: Wood and wood-based products for use in construction, Version 2019-12-20, UN CPC 031, 311-316, 319	Wooden panels	**Raw birch plywood (Riga Ply**	1m3 of plywood.	A1-A3	-	AS Latvijas Finieris	16-11-2021	EN 15804+A1	Engels											
Environdec	EN 16485	Wooden floors	**Wood flooring - TARKETT**	1m2 of floor covering with a reference service life (RSL) of 1 year for specified characteristics application and use areas according to EN 13489:2017 and EN 14342:2013.	A1-A5, B2, C2-C4	1	Tarkett	23-7-2020	EN15804+A1	Engels											
Environdec	SUB-PCR to PCR 2012:01: Wood and wood┐based products for use in construction. PCR 2012:01-SUB-PCR-E (Date: 2018-11-22)	Wooden board	**Oriented strand board (OSB)**	s 1 m3 of wood-based panel products manufactured at the Inverness site with an apparent density of 600 kg/m3	A1-A4	-	Norbord	31-1-2020	EN15804	Engels											
Environdec	PCR 2012:01 - Construction products and construction services. Ver 2.3 • Sub-PCR Wood and wood-based products for use in construction (EN 16485)	Wooden board	**Radiata pine sawn board**	1 m3 of radiata pine sawn board	A1-A3		BaskEugr	Revised 15-10-2021	EN15804	Engels											
Environdec	PCR 2012:01 - Construction products and construction services. Ver 2.2 • Sub-PCR Wood and wood-based products for use in construction (EN 16485)	laminated timber	**Radiata pine laminated wood**	1m3 of radiata pine laminated wood used as beam	A1-A3	-	Olatek	29-9-2018	EN 15804+A1	Engels											
Environdec	PCR 2012:01 - Construction products and construction services. Ver 2.2 Sub-PCR. Wood and wood-based products for use in constructio	laminated timber	**EGO-CLT Cross Laminated Timber wood pa**	1 m3 of EGO-CLTTM cross laminated tir	A-A5, B1-B7, C1-C4, D	100	Egoin	23-5-2018	EN 15804:A1	Engels											
Environdec	16485	Plywood	**WISA® Spruce plywood, uncoated**	1m3 plywood product throughout its who	A-A5, B1-B7, C1-C4, D	100	UPMBiofore beyond fossils	12-11-2021	EN15804:A2	Engels										Ecoinvent (3.7.1)	
Environdec	2019:14, v.1.0 Construction Products	Planed wood products	**Planed products wood panel and wooden la**	• 1 m3 planed product, bare wood, untreated • 1 m3 planed product, surface-treated for indoor use • 1 m3 planed product, surface-treated for outdoor use, primed	A1-A3, C1-C4, D		Lundgrens Hyvleri	revision 14-9-2021	EN15804:A2	Engels											
Environdec	PCR 2019:14 Construction products, version 1.11	HPL	**HPL boards with natural wood finish ProdE**	"1m2 of board (several types)	A1-A3, C1-C4, D		Prodema, natural wood s.l.	31-5-2021	EN15804:A2	Engels											
Environdec	PCR 2019:14 bouwproducten	composiet	**Fiberdeck hout kunststof composiet producten**	1kg hout-kunststofcomposiet	A-A5, B1-B5, C1-C4, D	25	Fiberdeck SAS	1-9-2021	EN15804:A2	Engels											
Environdec	: PCR Construction Products (2019:14), version 1.1 and c-PCR-006 Wood and wood based products for use in construction (EN16485:2014)	mouldings	**Painted and natural wooden mouldings - Pine, oak and MDF**	1 meter of wood moulding, with standard dimensions.	A1-A3, C1-C4, D	60	EHL Hoovelliist	10-9-2021	EN15804:A2	Engels											
Environdec	PCR 2019:14 Construction products	HPL	HPL boards with natural wood finish Facade ar	"1m2 of board" several types	A1-A3, C1-C4, D	-	Parklex	revision 31-05-2021	EN15804:A2	Engels											
Environdec	PCR 2019:14 Construction Products Version 1.0 (2019-12-20)	composite	**NewTechWood Wood Plascitc Composite**	1 kg of wood plastic composite	A-A5, B1-B5, C1-C4, D	25	Newtechwood	revision 31-05-2021	EN15804:A2	Engels											
Environdec	Construction products, PCR 2019:14 version 1.11	Compound product	**Factory finsihed panel with woodcore panel, galvanized steel dish and top covering**	1 m2 of panel	A-A5, B1-B7, C1-C4, D	25	CBI Europe	20-5-2021	EN15804:A2	Engels	**several more…** **https://www.environdec.com/library**										
FDES, Inies	NF EN 15804+A1 ET NF EN 15804/	Structural timber products	MUR OSSATURE BOIS EN BOIS DE FRANC	Constituer 1 m² de mur porteur stable qui délimite la structure d'un bâtiment sur la durée de vie de référence de 100 ans	A1-A5, B, C1-C4, D	100	Fédération Nationale du	mei-21	NF EN 15804+A1	Frans		in line with 15804 and 16485	no production waste declared	8,16kg wood 7,28kg wood panels 0,36kg metal connectors 0,05kg plastic packaging	Wood part: 57,2% recycling 17,3% landfill 25,5% energy recovery	A1-A3: -18,3kg A4: 0,28kg A5: 1.18kg B: 0 C1: 1.1.kg C2: 0,076kg C3: 21,9 kg C4: 1,44kg D: -9,96 kg Som: -2,28 kg		States that all forests in France are managed sustainably, therefore CO2 capture accounted.			no
FDES, Inies	NF EN 15804+A1 ET NF EN 15804/CN	oriented strand board	Panneaux de lamelles de bois minces orientées OSB (oriented strand board) de type 3 (panneaux travaillants utilisés en milieu humide) bruts	Assurer des fonctions structurelles (voiles de contreventement, dalles de plancher, etc.) sur 1 m² par des panneaux de lamelles de bois minces orientées OSB (oriented strand board) de type 3 (panneaux travaillants utilisés en milieu humide) bruts, d'épaisseur 18 mm, fabriqués en France, sur une durée de vie de référence de 100 ans. Le cadre de validité de cette FDES collective couvre l'ensemble des panneaux OSB 3 fabriqués en France, dans la limite d'une épaisseur maximale de 25 mm (cf. section correspondante à la fin de la FDES).	A1-A5, C1-C4, D	100	Institut technologique FCBA	15-10-2019	NF EN 15804+A1	Frans	All emissions included. 0,0000000000008% unmodelled flows in LCI from unspecified raw materials	In line with 16485.	0,887kg product at A5	wood 11.1kg (616kg/m3) 4,8% humidity. Screw (steel), 0,024kg	avg. French scenario. 67% recyling, 16% incineration, 17% landfill	A1-A3: -16,8 A4: 0,298 A5: 1,85 C1: 0 C2: 0,075 C3 :10,6 C4: 5,93 D: -3,66 sum: 1,72kg CO2eq	Why is A1-A3 larger than C3+C4?	Special section on biogenic carbon. 18,4kg biogenic CO2eq stored for 100 years. Contribution to climate mitigation of -15,7kg CO2eq following EN 16485 and PAS 2050. There is a biogenic content of 10,1kg			no
EPD Italyl	PRODOTTI E SERVIZI PER LE COSTRUZIONI (2019)	Wooden floors	Pavimenti in legno Collezione Garbelotto	1 m2 of product for wooden flooring	A1-A3, A5	-	Parchettificio Garbelotto	21-4-2021	EN 15804:A1	Italian	all exclusion < 5%	based on mass		For SP09 Wood, noble: 2,19 kg / m2 Glue 0,10kg / m2 birch multilayer, 3,9kg/m2 paint 0,09kg/m2	not declared	A1A3: 16,5 A5: 4,78 sum: 21,27 kg	Biogenic CO2 is not considered. Also no benefits.	Biogenic CO2 is not considered	No, is not full life cycle. There should be biogenic carbon in the product. This is not considered in the EPD.		

Annex V

GHG emission targets 2021-2030/2050 for EU-27

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												***GHG emision level of 2005***	
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2050**	Ton CO2eq	Mton CO2eq
Belgium	71,1	69,1	67,1	65,1	63,1	61,1	59,1	57,1	55,1	53,0	4,1	81605589	81,6
Bulgaria	27,1	25,2	24,8	24,5	24,1	23,7	23,4	23,0	22,7	22,3	1,1	22326386	22,3
Czechia	66,0	60,9	60,3	59,7	59,0	58,4	57,8	57,1	56,5	55,9	3,2	64965295	65,0
Denmark	32,1	31,3	30,5	29,6	28,8	28,0	27,1	26,3	25,5	24,6	2,0	40368089	40,4
Germany	427,3	413,2	399,1	385,1	371,0	356,9	342,8	328,7	314,7	300,6	24,2	484694619	484,7
Estonia	6,2	6,0	5,9	5,8	5,8	5,7	5,6	5,5	5,5	5,4	0,3	6196136	6,2
Ireland	43,5	42,4	41,2	40,1	39,0	37,9	36,7	35,6	34,5	33,4	2,4	47687589	47,7
Greece	46,2	47,0	47,7	48,5	49,2	49,9	50,7	51,4	52,2	52,9	3,1	62985180	63,0
Spain	201,0	198,7	196,3	194,0	191,7	189,4	187,0	184,7	182,4	180,1	12,1	241979192	242,0
France	335,7	326,5	317,3	308,1	298,8	289,6	280,4	271,2	262,0	252,7	20,1	401113722	401,1
Croatia	17,7	16,5	16,6	16,6	16,6	16,7	16,7	16,7	16,8	16,8	0,9	18056312	18,1
Italy	273,5	268,8	264,0	259,3	254,6	249,8	245,1	240,3	235,6	230,9	17,2	343101747	343,1
Cyprus	4,1	4,0	3,9	3,8	3,7	3,6	3,5	3,4	3,3	3,2	0,2	4266823	4,3
Latvia	10,6	8,9	8,8	8,7	8,6	8,5	8,4	8,3	8,2	8,1	0,4	8597807	8,6
Lithuania	16,1	13,7	13,5	13,3	13,0	12,8	12,6	12,3	12,1	11,9	0,7	13062124	13,1
Luxembourg	8,4	8,1	7,9	7,6	7,4	7,1	6,8	6,6	6,3	6,1	0,5	10116187	10,1
Hungary	49,9	43,3	43,5	43,6	43,8	43,9	44,1	44,2	44,3	44,5	2,4	47826909	47,8
Malta	2,1	1,2	1,2	1,1	1,1	1,0	1,0	0,9	0,9	0,8	0,1	1020601	1,0
The Netherlands	98,5	96,7	94,8	93,0	91,2	89,3	87,5	85,7	83,8	82,0	6,4	128112158	128,1
Austria	48,8	47,4	46,0	44,7	43,3	41,9	40,6	39,2	37,8	36,5	2,8	56991984	57,0
Poland	215,0	204,4	201,2	198,0	194,9	191,7	188,5	185,3	182,2	179,0	9,6	192472253	192,5
Portugal	42,5	40,8	40,8	40,7	40,7	40,6	40,6	40,5	40,5	40,4	2,4	48635827	48,6
Romania	87,9	76,9	76,9	76,9	76,8	76,8	76,7	76,7	76,7	76,7	3,9	78235752	78,2
Slovenia	11,4	11,1	11	10,9	10,8	10,6	10,5	10,4	10,3	10,2	0,6	11826308	11,8
Slovakia	23,4	21,2	21,5	21	20,9	20,8	20,7	20,6	20,5	20,4	1,2	23137112	23,1
Finland	28,8	28	28	26,2	25,6	24,5	23,6	22,7	21,9	21	1,7	34439858	34,4
Sweden	31,1	30,7	30,1	29,5	28,9	28,3	27,7	27,1	26,5	25,9	2,2	43228505	43,2
Total (Mton CO2eq)	*2226,1*	*2142,0*	*2100,0*	*2055,3*	*2012,2*	*1968,6*	*1925,1*	*1881,8*	*1838,6*	*1795,2*	*125,9*	*Total 2005*	*2517,1*
Reduction requirement compared to 2005	*290,9*	*375,1*	*417,1*	*461,7*	*504,8*	*548,5*	*591,9*	*635,2*	*678,5*	*721,8*	*2391,2*		