Technical Report

ISO/TR 25078

Wood and wood-based products — Examples of calculating displacement potentials for wood-based products and considerations for further analyses

Bois et produits à base de bois — Exemples de calcul des potentiels de déplacement pour les produits à base de bois et considérations pour d'autres analyses

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Foreword

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This document was prepared by Technical Committee ISO/TC 287, *Sustainable processes for wood and wood-based products*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

ISO 13391-1 defines a framework for calculating greenhouse gas dynamics of wood and wood-based products, see Figure 1. The framework identifies the displacement potential relating to displacing alternative products by using wood and wood-based products. This includes quantification of the value chain emissions of both the wood-based product and the alternative product, as shown in Figure 1. Displacement is composed of two parts, the greenhouse gas emissions related to the wood-based product(s) and the potentially prevented greenhouse gas emissions related to the alternative product(s), see Figure 1.

ISO 13391-1 provides calculation guidance for all aspects of the greenhouse gas emissions related to the wood-based product's value chain. ISO 13391-3 considers the emissions of alternative products and further elaborates on the calculation of displacement potentials. This document provides additional background and examples to users of ISO 13391-1 and ISO 13391-3. It includes aspects of the calculations as such, and also the wider context of analysing factors that can affect to what extent the displacement potential is realised.

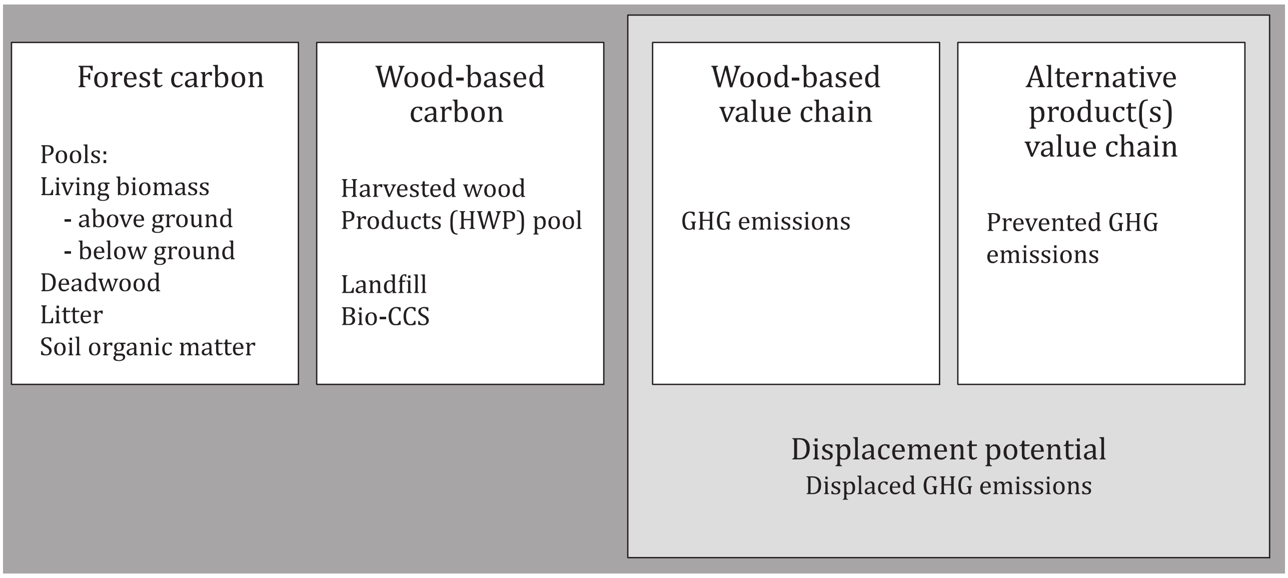

Figure 1 — Illustration of the components of the greenhouse gas dynamics of wood and wood-based products

This document provides background and examples in the following areas:

— Clause 4: Approaches for identifying alternative products, i.e. products with similar functionality but with different material origins that can be displaced by wood-based products. This pairing of alternatives is a basis for the calculation of displacement potentials.

— Clause 5: Examples of how to establish displacement factors, i.e. the quantity of greenhouse gas emissions avoided through displacement (in carbon dioxide equivalents) per unit of biogenic carbon (in carbon dioxide equivalents) contained in the wood-based product(s). The displacement factors are thus expressed in t CO_2e/t CO_2e and are as such unitless.

— Clause 6: Examples of tier 1 displacement factors for broad product categories based on the literature.

— Clause 7: Review of factors that can influence realisation of displacement potentials in society, including the development of the wider economy and consumption patterns.

Wood and wood-based products — Examples of calculating displacement potentials for wood-based products and considerations for further analyses

1 Scope

This document provides examples and background literature for identifying and calculating greenhouse gas displacement potential for wood-based products as defined in ISO 13391-3:2025, including the calculation of displacement factors.

This document also provides a review of considerations for further analyses that address the impact of these potentials over time in a broader economy setting.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13391-1:2025, *Wood and wood-based products — Greenhouse gas dynamics — Part 1: Framework for value chain calculations*

ISO 13391-3:2025, *Wood and wood-based products — Greenhouse gas dynamics — Part 3: Displacement of greenhouse gas emissions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13391-1 and ISO 13391-3 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Establishing alternative products

Defining the functional unit is fundamental when calculating displacement factors and working with value chain emissions estimates for alternative products. This is in order to allow for an objective comparison between the alternative product and the wood or wood-based product. As per ISO 14040:2006, a functional unit is defined as the "quantified performance of a product system for use as a reference unit". It is best practice to apply expert judgement when establishing the alternative product to ensure functional equivalence. However, it is important to recognize that a specific material can fulfil more than one function. For instance, in the case of a concrete shear wall, the wall provides structural capacity, a barrier to sound transmission, as well as fire protection. In comparison, a wood-framed wall might only provide structural capacity, and additional materials such as acoustic insulation and gypsum board are needed to meet the sound transmission and fire protection requirements, respectively. Therefore, when establishing the alternative product to a wood-based product to evaluate the displacement potential, it is best practice to examine the functional unit from a system perspective.

Functional units for construction products can be based on building components providing a specific function (e.g. 9 m × 9 m floor plate that supports an office space) or a complete building system (e.g. 4-storey residential building). A life cycle assessment (LCA) can then be performed to determine the emissions of both the wood-based product and alternative options in order to determine the displacement potential. Environmental Product Declarations (EPD) can be used to perform the assessment. However, a direct comparison of the EPD results between the wood-based product and an alternative product can only be performed when the EPD is based on the same declared unit with functional equivalency, and the conditions for comparing EPDs in ISO 14025 are met.

Similarities between the wood-based product and the alternative product can be defined to simplify the analysis. For instance, when the functional unit is defined as a building, it can sometimes be assumed that the operational energy use for the wood building is the same as the operational energy use for the alternative (e.g. concrete or steel) building. Similarly, the scope of the functional unit can be defined to simplify the comparison, for example limiting the functional unit to just the superstructure of the building. This approach would not capture the impact of the mass of the superstructure in the foundation design, but the results of the study can be more broadly applied if repeatable construction is being considered e.g. where the building structure is being repeatedly constructed in multiple locations.

It is also important to account for the geographical location where the alternative product is manufactured and used. The energy production system, technological efficiency, and electrical grid will all impact the emissions of the manufacturing, use, and end of life stages of the wood-based and alternative product. Emissions will also reflect the geographically relevant manufacturing processes, use conditions, and end of life processes.

Equivalence between the system boundary of the alternative product and the system boundary of the wood-based product is necessary to ensure consistency for the comparison. A comprehensive study would consider the full life cycle, including raw material extraction, processing, transportation, manufacturing, distribution, use, re-use, maintenance, replacement, and final disposal. This approach is often referred to as 'cradle-to-grave'. Another commonly used approach is 'cradle-to-gate' and can be selected where only the stages up to the end of manufacture are currently available. Establishing the processes for life cycle stages beyond the manufacturing gate will require assumptions, and there will therefore be inherent uncertainties in the study and reduce the representativeness of the results. Additionally, since there is no guarantee of the exact destiny of the product, providing a description of each plausible scenario in a report provides transparency about the analysis, the assumptions and the results.

An evaluation of the products that are readily available on the market and commonly used to perform the required function within the defined temporal boundary assists in establishing the alternative product. It is entirely possible that a single wood-based product can displace several other products, so a representative set of alternative products would then be selected. It is equally possible that some wood-based products do not displace any other products at all, for example where the wood-based product is the market leader or default choice for a given application, e.g. paper within books. It would be possible to compare a printed book with an e-reader, but at this current time the e-reader is not the item being displaced, it is in fact displacing the book.

Many studies are careful to do this based not only on functional equivalence, but also market share of the various alternative products, i.e. assigning factors based on the proportion of the various products that can be displaced by the wood-based product.

5 Establishing displacement factors for wood-based products

5.1 General

Clause 5 provides calculation examples for the establishment of displacement factors based on the literature. It includes consideration of greenhouse gas emissions in the wood-based product(s) value chain as well as the emissions from alternative products.

NOTE 1 'Emissions from alternative products' is a term defined in ISO 13391-1.

This document also deals with situations that do not lead to displacement.

As per ISO 13391-3, the displacement factor for a specific use of wood-based product(s) is calculated as given in Formula (1):

$$f_{\mathrm{D,spec}} = \frac{m_{\mathrm{E,ap}} - m_{\mathrm{E,w}}}{w_{\mathrm{B,w}} - w_{\mathrm{B,ap}}} \tag{1}$$

where

$f_{\mathrm{D,spec}}$ is the displacement factor for a specific use of the wood-based product in a specific geographical scale, expressed in t CO_2e/t CO_2e;

$m_{\mathrm{E,ap}}$ is the quantity of emissions from alternative products with functional equivalence to the wood-based product considered, expressed in t CO_2e;

$m_{\mathrm{E,w}}$ is the greenhouse gas emissions related to the wood-based product considered, expressed in t CO_2e;

$w_{\mathrm{B,w}}$ is the quantity of biogenic carbon in the wood-based product placed on the market in the specified time period, expressed in t CO_2e;

$w_{\mathrm{B,ap}}$ is the quantity of biogenic carbon in the alternative product, expressed in t CO_2e.

NOTE 2 Formula 1 is the equivalent of a widely recognized formula used in e.g. Sathre and O'Connor,[44] but the symbols have been re-drafted in accordance with ISO drafting rules.

Two other useful formulae from ISO 13391-1 is for converting wood volume to carbon dioxide equivalents in two steps.

The mass of wood at dry condition can be calculated using Formula 2:

$$m_{\mathrm{dry}} = \frac{\rho_\omega \times V_\omega}{1 + \frac{\omega}{100}} \tag{2}$$

m_{dry} is the mass of wood at oven dry condition (moisture content of 0 %)

ω is the gravimetric moisture content of wood (e.g. 12 % mass of water per mass of dry wood);

ρ_ω is the density of wood at moisture content of ω;

V_ω is the volume of wood at moisture content of ω;

The biogenic carbon content in wood can be calculated using Formula 3:

$$w_{\mathrm{B}} = \frac{44}{12} \times w_{\mathrm{C,f,dry}} \times m_{\mathrm{dry}} \tag{3}$$

where

w_{B} is the biogenic carbon in wood expressed in carbon dioxide equivalents (CO_2e);

$\frac{44}{12}$ is the molecular mass ratio of CO_2/C;

$w_{\mathrm{C,f,dry}}$ is the carbon fraction in wood at oven dry condition, 0,5 as the default value.

ISO 13391-3 further details how displacement factors are calculated for sets of wood-based products, divided into first use (including recycled material) and final use (recovery for energy purposes). This clause, however, only deals with examples of calculating displacement factors for specific use(s) of wood-based product(s).

ISO 13391-3 requires that data sources and displacement factors used in calculations are transparently documented, including the alternative product(s) and product system(s) used with justification.

Determining displacement factors for specific uses can be complicated and depends on consideration of a range of factors including:

— ISO 13391-3, requires that the functional unit is based on the intended function or service of the product and defined as the quantified performance of a product system in terms of its unit, magnitude, and if relevant, duration, reuse, and level of quality;

— ISO 13391-3, recommends that system boundaries suitable for conducting the life cycle assessment (LCA) of the wood-based product are defined. It is required that the system boundaries, including choices made, are transparently documented and justified;

— Displacement factors can vary with geographical location depending on variations of greenhouse gas emissions in both of the compared product's value chains for a specified functional unit;

— Calculations can refer to comparable parts in the value chain where the system boundary is defined equivalently. The starting point is the “cradle” to account for all upstream emissions. The “gate”, representing delivery of the product(s) to the customer is often used as the other boundary, under the assumption that emissions further downstream are of similar magnitudes for the alternative products. A “cradle-to-grave” boundary can therefore be more accurate for determining the displacement factor so as to account for the entire value chain in the comparison, although data for downstream emissions of reasonable quality and comparability can be difficult to obtain;

— Wood-based value chains are complex and integrated. While displacement factors for individual products at the consumer end can be straightforward to calculate, the displacement factors of products in the upstream value chain (e.g. sawn wood, wood-based panels, paper, wood pulp, wood-based energy products and roundwood) requires aggregations and weighting of downstream product mixes, depending on the set of identified alternatives.

5.2 Types of data sources

Calculation of displacement factors builds on documented data from different types of publications, including:

— Published scientific articles, including both review articles and articles addressing specific topics, such as housing construction, that have been published over the past 20+ years.

  — The level of data detail can be lower than for LCA studies as the study in question can address a broader question where displacement factors are only a part.

  — As the literature is not standardized in the way that LCA studies are, it can be challenging to extract data that correspond with the applied system boundary. Analyses are not always documented to make the extraction of the relevant data possible, which can lead to excluding a study for data quality reasons.

— Comparative life cycle assessments (LCAs).

  — LCAs include standardized approaches to calculate and compare performances of products, see for example ISO 14044. This provides a good foundation for extracting data for calculation of displacement factors.

  — LCAs can address very specific products in specific market contexts which can make it difficult to generalize the findings. For example, the alternative product(s) chosen are not always representative for the overall market, in which case the displacement factor would also not be representative.

  - — In situations where several LCAs are available for comparing the wood-based product(s) to alternatives, an approach for utilizing the full set of information is to calculate a weighted mean or median of specific-use displacement factors across the studies.
- — Life cycle assessments and environmental product declarations (EPDs).
  - — Where no comparative LCA is available it can be possible to obtain the required information for the wood-based product or the alternative product directly from individual LCAs or EPDs. This is considered further in 5.3.

5.3 Calculation approaches to determine value chain emissions of wood-based and alternative products

This clause builds on establishing a functional unit for the products or product systems that are to be compared, see Clause 4.

The greenhouse gas emissions for the wood-based product, and all identified alternative products, can be determined using EPDs or LCAs. In addition to the functional equivalence, the relevant geographical region and energy mix are important as they can have different global warming potential depending on the location of manufacture, the process efficiencies at the particular factory and other factors. The more specific the data is (e.g. facility-specific, process specific, region specific, etc.), the more accurate the results will be. If EPDs or LCA data are not provided on a granular scale, national databases that provide average emission factors for products can be referenced.

5.4 Calculation examples, including data sources

5.4.1 Example 1 – Wooden pallet vs. Plastic pallet

Case 1:

Based on a global review of published EPDs, two pallet EPDs were found from the same manufacturer, one for wooden pallets and one for plastic pallets.[45][46] These studies used the same system boundary, regional data and functional unit i.e. one loop usage of the plastic or wooden pallet (1 200 × 800 mm) in the system. The greenhouse gas emissions were reported to be 0,294 kg CO_2e and 0,478 kg CO_2e for the wooden and plastic pallet, respectively. The amount of solid wood used in the functional unit of wooden pallet is estimated at 1,04 kg. Following the formula in ISO 13391-3 for determining the biogenic carbon content, the $w_{B,w}$ is calculated here (assuming pallet wood with a moisture content of 20 %):

$$w_{B,w} = \frac{44}{12} \times 0{,}5 \times \frac{1{,}04}{1+20\,\%} = 1{,}589 \text{ kg } CO_2\text{e}$$

There is no biogenic carbon content in the plastic pallet, thus $w_{B,ap} = 0$;

Then using the formula for $f_{D,spec}$:

$$f_{D,spec} = \frac{m_{E,ap} - m_{E,w}}{w_{B,w} - w_{B,ap}} = \frac{0{,}478 - 0{,}294}{1{,}589 - 0} = 0{,}12$$

Case 2:

Deviatkin and Horttanainen[16] compare the carbon footprint of EUR-sized wooden and plastic pallets, taking into account a wide range of factors for the functional unit, including number of re-use rounds and repairs. The functional unit was set to 1 000 utilizations. The greenhouse gas emissions for the plastic pallet was 15 × 62 = 939 kg CO_2e (15 pallets needed for the functional unit). Biogenic carbon content of the wooden pallet (50 pallets needed for the functional unit) was 50 × 36,0 = 1 798 kg CO_2e, including material for repairs. The greenhouse gas emissions for the wooden pallet functional unit (cradle-to-gate) was 50 × 5,0 = 250 kg CO_2e. Calculations refer to first use and do not include displacement at final use for energy.

$$f_{\mathrm{D,spec}} = \frac{m_{\mathrm{E,ap}} - m_{\mathrm{E,w}}}{w_{\mathrm{B,w}} - w_{\mathrm{B,ap}}} = \frac{939 - 250}{1798 - 0} = 0{,}38$$

Table 1 — Calculated displacement factor (f_D) for first use of wooden pallet based on References [16][45][46]

Pallets	$w_{B,w}$	$m_{E,w}$	Displaced product	$m_{E,ap}$	Calculated f_D
	kg CO_2e/FU	kg CO_2e/FU		kg CO_2e/FU	t CO_2e/t CO_2e
Case 1: Wooden pallet	1,589	0,294	Plastic pallet	0,478	0,12
Case 2: Wooden pallet	1 798	250	Plastic pallet	939	0,38

These two cases in Table 1 demonstrate how a simple change in functional unit can lead to a large difference in the displacement factor value obtained.

5.4.2 Example 2 – Wood-based bioenergy displacing fossil energy sources

Wood-based bioenergy can displace different forms of fossil-based energy, thereby displacing greenhouse gas emissions. The displacement factor will vary depending on the alternative fossil energy source, and the efficiency in energy production and delivery in both the wood-based and the fossil-based system considered. Energy production is relatively well investigated, which means that emission factors for a variety of systems are available, including for electricity only, heat only, or combined heat and power production (CHP). Among fossil-based energy sources, and compared with oil combustion, coal combustion generates higher relative greenhouse gas emissions and natural gas lower relative greenhouse gas emissions. This means that the displacement factor is higher when biomass replaces coal, and lower when biomass replaces natural gas.

When wood-based electricity (for example as part of the output from a CHP facility) displaces alternative electricity production for the grid, assigning an emission factor for the alternative production becomes significant. For example, in a European context, there will be a large difference between the average emissions from electricity production ("the European mix"), compared with high-emission production from coal-fired plants on the margin of the European grid. Either of these assignments can be valid for the calculations at hand but will lead to different results. See also 7.4 for further elaboration on this topic.

Case 1:

Based on the published research papers[43][37], LCA studies were performed to determine the greenhouse gas emissions factors for heating with wood pellet and heating with anthracite coal. The greenhouse gas emission factors were determined to be 37 kg CO_2e/GJ, and 103 kg CO_2e/GJ for the wood pellets and anthracite coal respectively. Based on the estimation of oven dry wood heating value of 19 MJ/kg, it will require 52,63 kg of wood to produce 1 GJ of heating. The biogenic carbon content in wood pellets is calculated as

$$w_{\mathrm{B,w}} = 52{,}63 \times 0{,}5 \times (44/12) = 96{,}58 \text{ kg } CO_2$$

Then the displacement factor of wood pellet heating to displace coal heating is

$$f_{\mathrm{D,spec}} = \frac{m_{\mathrm{E,ap}} - m_{\mathrm{E,w}}}{w_{\mathrm{B,w}} - w_{\mathrm{B,ap}}} = \frac{103 - 37}{96{,}58 - 0} = 0{,}68$$

Case 2:

Cintas et al published a study[13] on the impacts of increased bioenergy production in Sweden, including impacts on the forest. As part of the calculations, emissions in modern CHP facilities were compared between biomass sourced from side streams of forest harvesting, natural gas and coal, taking into account conversion efficiencies and supply chain emission factors. Details of the calculations are found in the referenced article. For biomass replacing coal, the displacement factor was calculated to 1,27 t CO_2e/t CO_2e and for biomass replacing natural gas 0,55 t CO_2e/t CO_2e.

Table 2 compares the three results above.

Table 2 — Calculated displacement factors for wood-based bioenergy based on[13],[37],[43]

Bioenergy	$w_{B,w}$	$m_{E,w}$	Displaced product	$m_{E,ap}$	Calculated f_D
	kg CO_2e/FU	kg CO_2e/FU		kg CO_2e/FU	t CO_2e/t CO_2e
Case 1: Wood pellets	96,58	37	Coal-based heating	103	0,68
Case 2: Biomass in CHP facility			Coal		1,27
Case 2: Biomass in CHP facility			Natural gas		0,55

5.4.3 Example 3 – Cross-laminated timber (CLT) floor to displace concrete floor.

A typical floor slab designed for mass timber building in the US, following the International Building Code (IBC) 2021 normally contains 5-ply CLT panel (180 mm-thick) with 7,9 mm-thick (5/16”) sound mat for acoustic control and 50,8 mm-thick (2”) gypcrete on top for vibration control, see Figure 2 (left). The displaced functionally equivalent concrete floor slab using reinforced concrete as the main structural material contains 5 000 psi concrete with a rebar density of 18,8 kg/m^2 (1,75 kg/sq ft) and post tension cable intensity of 8,6 kg/m^2 (0,8 kg/sq ft).

Figure 2 shows the two flooring slabs.

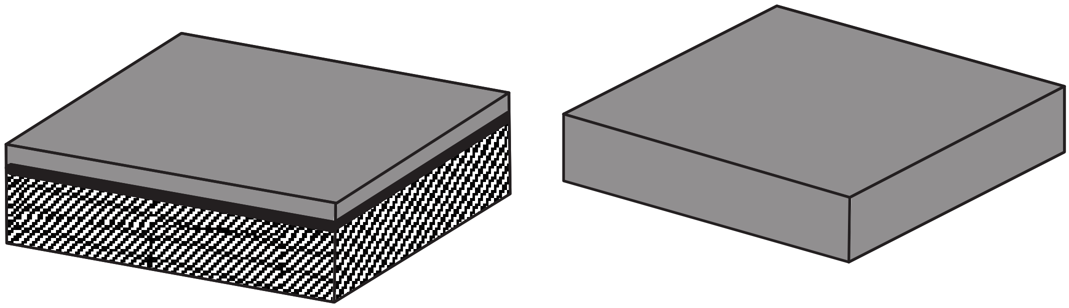

Figure 2 — 1 m^2 floor system for cross-laminated-timber (left) and concrete (right)

Using these product systems, a specific cradle-to-gate LCA was conducted on the two systems to estimate the greenhouse gas emissions based on the systems’ value chains.

The greenhouse gas emissions from the product stage of the two floor systems show:

For the CLT floor: $m_{E,w}$ = 49,1 kg CO_2e/m^2

For the concrete floor: $m_{E,ap}$ = 258,9 kg CO_2e/m^2

The biogenic carbon content in the CLT floor is calculated as:

$$w_{B,w} = \frac{44}{12} \times 0,5 \times \frac{(V \times \rho)}{(1+\omega\ \%)} = \frac{44}{12} \text{ x } 0,5 \times \frac{\left(0,174\,6\ \text{m} \times 1\ \text{m}^2 \times \dfrac{500\ \text{kg}}{\text{m}^3}\right)}{(1+15\ \%)}$$

$$= 146,7\ \text{kg } CO_2\text{e}$$

$$w_{\mathrm{B,ap}}=0$$

Then the displacement factor for this case is:

$$f_{\mathrm{D,spec}}=\frac{m_{\mathrm{E,ap}}-m_{\mathrm{E,w}}}{w_{\mathrm{B,w}}-w_{\mathrm{B,ap}}}=\frac{258,9-49,1}{146,7-0}=1,43$$

The results are summarized in Table 3.

Table 3 — Calculated displacement factor for cross-laminated timber (CLT) floor

Flooring	$w_{\mathrm{B,w}}$	$m_{\mathrm{E,w}}$	Displaced product	$m_{\mathrm{E,ap}}$	Calculated f_{D}
	kg CO_2e/FU	kg CO_2e/FU		kg CO_2e/FU	t CO_2e/t CO_2e
Cross-laminated flooring	146,7	49,1	Concrete flooring	258,9	1,43

5.4.4 Example 4 - Packaging of beverages

The Swedish alcohol beverage monopoly commissioned a comparative LCA of different packaging solutions for wine.[20] The three comparisons in Table 4 have been extracted from the study as an illustration. Numbers represent the functional unit (FU) of 1 l of packaged beverage.

Calculated displacement factors were high especially when the alternative product is glass bottles, even though 83 % of the glass material was recycled. Both energy intensive production of glass bottles and higher mass in transport contributed to the results.

Table 4 — Calculated displacement factors for packaging of beverages based on[20]

Paper packaging product	$w_{\mathrm{B,w}}$	$m_{\mathrm{E,w}}$	Displaced product	$m_{\mathrm{E,ap}}$	Calculated f_{D}
	kg CO_2e/FU	kg CO_2e/FU		kg CO_2e/FU	t CO_2e/t CO_2e
3 l carton box	0,088	0,069	0,75 l glass bottles	0,609	6,2
1 l paper container	0,054	0,053	0,75 l PET bottle	0,253	3,3
1 l paper container	0,054	0,053	0,75 l glass bottles	0,609	9,9

5.4.5 Example 5 - Building structure

Mass timber (such as cross laminated timber [CLT] and glulam) is substituting concrete and steel structures with impressive speed for new building designs and constructions. An exponential increase of mass timber projects has been recorded within the US in the past 10 years.[55] In one case,[32] three functional equivalent building systems - mass timber, concrete and steel, complied to the 2024 IBC building code and US regional specification. The total greenhouse gas emissions of the three are quantified for the cradle-to-grave (end of building life) system boundary. The functional unit is the 12-story residential building with gross floor area of 12 900 m^2, and service life of 75 years. The primary structure, including substructure as foundation system and superstructure like floors, roofs, beams, etc, and enclosures, fire and acoustic assemblies are all included in the quantification of the whole building greenhouse gas emissions. Only the concrete and mass timber data are used here to show the calculation of the displacement factor in the whole building level. The two building systems are shown in Figure 3.

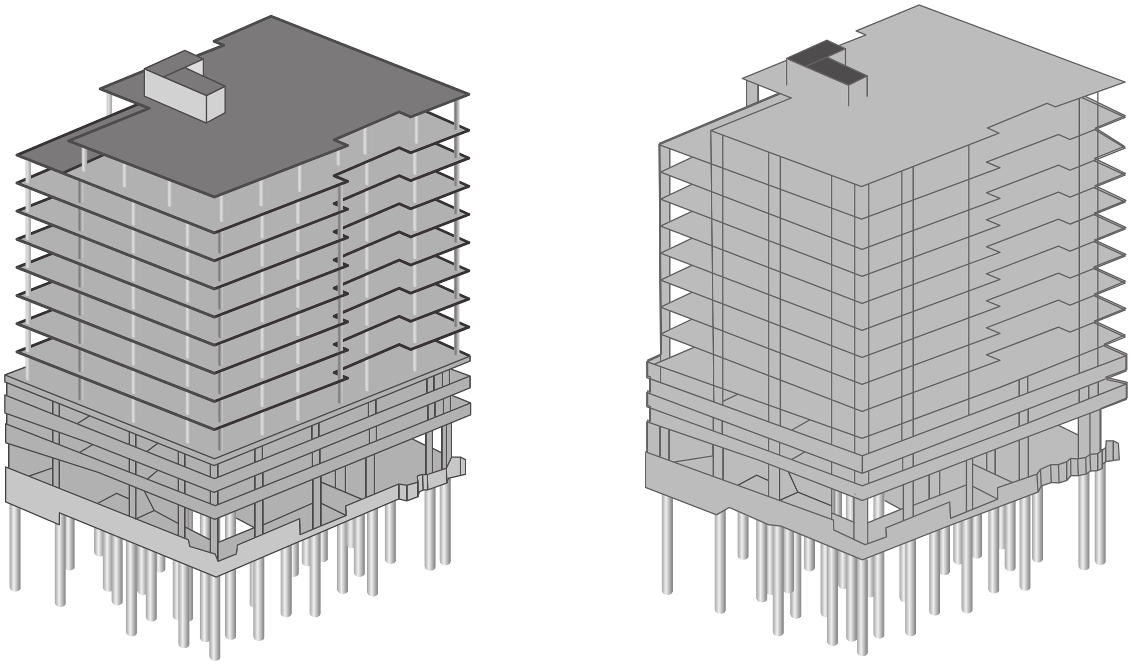

Figure 3 — Two functional equivalent buildings designed for mass timber (left) and concrete (right) structural systems

The total GWP impact is 2 616 100 kg CO_2e for the mass timber building, and 3 485 064 kg CO_2e for concrete. And the total mass of the CLT and glulam used in the mass timber structure is reported as 750 367 kg and 217 333 kg, respectively. No other wood-based materials are reported in the analysis.

If assuming 15 % moisture content in the mass timber products, the biogenic carbon is calculated as below.

For the mass timber building:

$$w_{\mathrm{B,w}} = \frac{44}{12} \times 0{,}5 \times \frac{\left(m_{\mathrm{CLT}} + m_{\mathrm{glulam}}\right)}{(1+\omega\ \%)} = \frac{44}{12} \times 0{,}5 \times \frac{(750\,367 + 217\,333)}{(1+15\,\%)}$$

$$= 1\ 542\ 710 \text{ kg CO}_2\text{e}$$

For the concrete building: $w_{\mathrm{B,ap}} = 0$

Then the displacement factor for this case is:

$$f_{\mathrm{D,spec}} = \frac{m_{\mathrm{E,ap}} - m_{\mathrm{E,w}}}{w_{\mathrm{B,w}} - w_{\mathrm{B,ap}}} = \frac{3\,485\,064 - 2\,616\,100}{1\,542\,710 - 0} = 0{,}563$$

The results are summarized in Table 5.

Table 5 — Calculated displacement factor for building structure using mass timber based on[32]

Mass timber structure	$w_{\mathrm{B,w}}$	$m_{\mathrm{E,w}}$	Concrete structure	$m_{\mathrm{E,ap}}$	Calculated f_D
	kg CO_2e/FU	kg CO_2e/FU		kg CO_2e/FU	t CO_2e/t CO_2e
12-story residential building with gross floor area of 12 900m^2	1 542 710	2 616 100	12-story residential building with gross floor area of 12 900 m^2	3 485 064	0,563

5.5 Literature review

NOTE The references sometimes use harvested wood products/HWP whereas this document uses wood-based products. In this clause, the terms used in the original source have been used.

This clause summarizes several published literature reviews of displacement factors for wood-based products and building systems. In addition, an extended literature search was made in preparing this document.

It is common to observe that displacement factors vary considerably between studies, even for very similar products and their functional alternatives. Some studies have calculated average displacement factors across national systems. Soimakallio et al.[49] used an average displacement factor for the whole national activity of Finland, with a value of 1,2 t CO_2e/t CO_2e based on a range from 0,7 to 1,7 t CO_2e/t CO_2e for different product types. They commented that this was higher than the value used in other national level studies, such as 0,4–0,8 t CO_2e/t CO_2e for Finland,[50] 0,5 t CO_2e/t CO_2e for Switzerland,[52] 0,6 t CO_2e/t CO_2e for Sweden[38] and 0,5 t CO_2e/t CO_2e for Canada[47].

The review by Leskinen et al. (2018) on more recent studies and meta-analysis suggested an overall displacement factor of 1,2 for wood-based products, see Table 6. The average displacement factor for structural construction was 1,3, and the average displacement factor for non-structural construction was 1,6.

Table 6 — Average displacement factors (substitution effects) for wood-based product categories (from[36])

Product categories	Average substitution effects kg C / kg C wood-based product
Structural construction (e.g. building, internal or external wall, wood frame, beam)	1,3
Non-structural construction (e.g. window, door, ceiling and floor cover, cladding, civil engineering)	1,6
Textiles	2,8
Other product categories (e.g. chemicals, furniture, packaging)	1,0 to 1,5
Average across all product categories	**1,2**

Sathre & O'Connor[44] reviewed 21 publications and summarized the displacement factors in the construction field. They found a wide range of displacement values across different wood-based products that displace alternative building products. The displacement factors ranged from a low of -2,3 to a high of 15, with most lying in the range of 1,0 to 3,0.

A recently published paper by Taylor et al.[54] provided displacement factors for various harvested wood-based products to displace alternatives, see Table 7.

Table 7 — Displacement factors for wood-based product categories (from[54])

Wood-based product	Alternative product	Displacement factor (t CO_2e avoided / t CO_2e in HWP used)
Primary construction Sawn wood, plywood and veneer, OSB, particle board, MDF	Steel	0,96
Floor Laminate, MDF	Ceramic tile, vinyl sheet	0,99
Floor Solid wood	Ceramic tile, vinyl sheet	1,59
Treated posts, poles and pilings Softwood or hardwood	Steel, concrete, fiberglass	1,4
Decking and fencing Solid wood	Wood-plastic composite	2,39
Pallets Sawn wood, plywood and veneer, OSB	Plastic	0,34
Furniture Sawn wood, plywood and veneer, OSB, particleboard, MDF, hardboard	Steel shelving	0,36
Packaging paper Mechanical or chemical pulp	Plastic	1,12
Heating or electrical power Energy wood, pellets	Fossil fuel mix	0,68

USDA Forest Service recently published a national guideline for forest landowners as a reference to quantify the greenhouse gas emissions and carbon sequestration at the entity-scale for agriculture and forestry.[40] In Chapter 5 of that document (the harvested wood products section), the displacement factors are presented for the typical HWP categories and wood to energy substitution, see Tables 8 and 9 extracted below from the guideline[40].

Table 8 — Displacement factors for material substitution: HWPs against non-wood-based products (from Reference [40])

HWP	Functionally equivalent non-wood-based product	Displacement factor (t CO_2e avoided / t CO_2e in HWP used	Reference
Softwood lumber	One steel stud	0,99	Adapted from Reference [6]
Hardwood lumber	One steel door	2,29	Adapted from Reference [6]
Plywood	Structural construction materials	1,3	[36]
Oriented strandboard	Structural construction materials	1,3	[36]
Other industrial products	Non-structural construction materials	1,6	[36]
Other industrial products	Non-construction use	1,2	[36]

Table 9 — Displacement factors for energy substitution: woody biomass against non-wood-based fossil energy and heating sources (from Reference [40])

HWP	Displacement factor (t CO_2e avoided / t CO_2e in HWP used)
Electricity[a]	
Mill residues	0,270[c]
Logging residues	0,267[c]
Softwood pulp	0,261[c]
Heat (wood-based fuel)[b]	
Coal	0,68[d]
Oil	0,57[d]
Natural gas	0,45[d]

[a] Emissions for grid-based electricity were taken from Reference [5] using the national average profile.

[b] The calorific value of wood chips at 30 percent moisture content (12,2 MJ/kg) was used[34].

[c] Displacement factors when the woody biomass generated electricity to displace the US grid-based electricity (mix of fossil and renewable sources).

[d] Displacement factors when wood-based fuel generated heat to displace the fossil fuel (coal, oil or natural gas) generated heat.

6 Examples of tier 1 displacement factors for selected products and product categories

Based on the previous clauses and an extended literature review (list of references in the Bibliography, including References [56] to [163] see also extracts from literature reviews referred to in 5.5), generic displacement factors were defined. These examples of displacement factors for broad product categories are listed in the table below.

Note that these examples are general indications that can be suitable for tier 1 applications, but deeper analysis of an organization's or entity's delivery of products to the market can lead to different results. In ISO 13391-3:2025, Table A.1 gives indicative displacement factors that can be used for a tier 1 approach.

If the organization chooses to report a displacement factor from this clause or from the literature in addition to calculated greenhouse gas emissions from the wood-based value chain, extra considerations and limitations can be described to avoid double-counting, since displacement factors from external sources can include or exclude the wood-based product value chain emissions. At minimum, ISO 13391-1:2025, 6.3.3 requires that a statement be included with a reported displacement factor, explaining some of its limitations. Most of the literature refers to displacement factors that include the wood-based value chain emissions. Reporting these emissions separately can lead to double-counting.

Displacement factors can be lower or higher if the wood-based value chain leads to different levels of greenhouse gas emissions compared with examples in the literature.

A deeper analysis can also lead to a more detailed set of product categories, which can in turn lead to higher or lower calculated displacement factors. For example, a certain portion of packaging solutions can replace glass or metal packaging, which would affect the displacement factor. Similarly, sawn wood products can be destined to specific applications that can justify a different displacement factor.

Overall, the tier 1 displacement factors in Table 10 below have been conservatively set in relation to the literature. The factors derived from the literature result in a wide range due to the variation of cases they cover, see 5.5 for examples. For this reason, a deeper analysis by an organization can be a useful exercise that can also help build a better understanding of the performance of specific wood-based value chains.

Table 10 — Indicative tier 1 displacement factors for first use of product categories (excluding displacement at final use)

Product category	Displaced products (examples)	Tier 1 displacement factor, first use t CO_2e/t CO_2e	Notes
Roundwood	Combination of products placed on the market after processing	0,5	Refers to volume under bark. Assumes that roundwood is used as sawn wood to the extent possible and for fibre-based products and energy for the remaining biomass. The indicated displacement factor includes consideration of downstream greenhouse gas emissions for the processing into sawn wood and fibre-based products and transport of these to customer gate. 1 example (the reference below) contributed data (displacement factor =0,55). Further consideration has been based on calculated combinations and typical utility proportions from roundwood of below product categories. Reference: [29]
Sawn wood	Various non-wood-based construction materials	1,2	Includes products based on sawn wood. 30 examples from the references below contributed data References: [6], [8], [9], [10], [11], [14], [19], [22], [30], [33], [36], [40], [42], [48], [50], [53], [54]
Wood-based panels	Various non-wood-based materials	1	2 examples from the references below contributed data. Given the low number of examples, the displacement factor is set conservatively (examples averaged 1,4) References: [30], [42], [48], [50], [40], [16], [45], [46]
Paper packaging	Packaging from plastic, glass or metal	1	Displacement of glass and metal packaging can lead to much higher displacement factors (5-10) but are not distinguished here. 20 examples from the references below contributed data References: [15], [18], [24], [30], [31], [35], [39], [51], [20], [41], [17], [12], [54]

Table 10 *(continued)*

Product category	Displaced products (examples)	Tier 1 displacement factor, first use t CO_2e/t CO_2e	Notes
Other fibre-based products, especially innovations or emerging products	Displaced product to be identified for the relevant market. Assigning a displacement factor can be based on specific data for the products, their relative volumes, and their relative displacement potentials.	Depends on and varies widely with the product delivered at the end of the wood-based value chain. If no data are available, the first use displacement factor can be set to 0 for this category.	High first use displacement factors (1-4) have been documented for some fibre-based products including for wood-based textiles and insulation materials. For other products, such as sanitation paper, the first use displacement factor can be negligible. In addition, final use energy recovery leads to displacement.
Solid biofuels	Corresponding energy product based on fossil fuels	By fossil fuel displaced: Unspecified fossil fuels: 0,7 Natural gas: 0,5 Oil: 0,7 Coal: 1	Depending on the fossil fuel displaced, and the production process for the wood-based fuel, the displacement factor can be higher or lower. 38 examples from the references below contributed data References: [13], [21], [23], [24], [26], [7], [42], [48], [50], [53], [40], [43], [37]

7 Factors that can influence realisation of displacement potential

7.1 General

The second word in the term “displacement potential” is included to indicate that there is no guarantee that the calculated level of displacement will be realised in full. Whilst the calculation of the displacement potential that will be realised is outside the scope of the ISO 13391 series, this clause introduces some of the issues to consider if such an assessment is desired.

An understanding of how market effects, time periods and potential biases influence the actual displacement can also assist with assessment and interpretation of displacement potential.

7.2 Market effects

There is a possibility that adding wood-based products to the market will to some extent grow the overall market, meaning that some of the wood is additional to existing materials production and consumption in other sectors, instead of displacing it. This part of the displacement potential is displacement that will not be realised in practice.

The impact of wood-based products taking a share of the non-wood-based sectors market can include price reductions in the non-wood-based sectors leading to a recovery in demand and increase in overall consumption, and the non-wood-based sectors expanding supply into other markets. Harmon[25] and Howard et al.[27] discuss this, and related effects, using the terms “carbon leakage” and “cross-sectoral leakage” respectively, and note that this is almost universally neglected.

Hurmekoski et al.[29] noted that “there are no established practices for the use of product-level displacement factors when upscaling the substitution impacts to cover an entire market, and recent literature indicates the existence of many complexities related to upscaling.” Subsequently, Hurmekoski[28] has sought to address this deficiency, and has outlined a method for assessing displacement using macroeconomic theory and econometric analysis, and tested it on the textiles market.

7.3 The time dimension

The displacement potential methodology provided in ISO 13391-3 allows for displacement from a product's first use, substituting a counterfactual product, and from energy recovery at the end of a product's life. However, the standard treats a product's first use and final use (including energy recovery), in different ways.

The displacement potential arising from the first use of a wood-based product arises from the quantity of that product placed on the market during a defined time period. By contrast, the corresponding displacement potential arising from the final use of the product is based on the proportion of other (similar) wood-based product material being recovered as it reaches the end of life during the same time period. Therefore, there is no causal link between the wood-based product placed on the market and the final use displacement calculated. Instead, the value is a proxy for the displacement that will arise when the newly marketed product eventually reaches the final use stage, potentially many decades into the future for some products.

It is important to remember that this estimation is based on the current market conditions for energy recycling of the wood-based products. In reality, when the product enters the final use stage, the displacement factors might be different depending on future sources for energy supply.

ISO 13391-3 provides one method to solve the time period issue, by calculating the displacement potential of final use with contemporary data and knowledge about energy recovery. However, there are other ways to deal with this. For example, it might be based on scenarios for the future final uses of material placed on the market, with future emissions and sinks discounted, various methodologies exist for taking this into account, for instance as set out in the ILCD Handbook[4].

7.4 Biases and choice of product system

Data availability and assumptions made to realize the calculations of the displacement potential can lead to bias and have an impact on the result. It is important to be aware of the possibility of systematic biases arising from assumptions made.

One such bias can be introduced through a failure to account for ongoing decarbonisation throughout the economy. The overall effect can be expected to be a downwards trend in displacement potential for a given product category, as the greenhouse gas emissions associated with its own production and with that of the alternative product reduce over time. Alternatively, product innovation in the wood-based sector might lead to an upwards trend. In either case, displacement factors used now will typically be based on data and studies accumulated over a number of past years and can therefore be years behind the trend. This might lead to inaccurate estimations of the displacement potential.

Another potential bias to consider is the choice of alternative product system. For example, when different options exist, it can be tempting to choose the product system that produces the most favourable result, although this is easily mitigated by producing a market assessment that explains the rationale for the product choice.

The choice of alternative product or product system becomes particularly complicated when it is part of a larger system. Electricity grids provide a good example. When wood-based fuel is burned in a power station to provide electricity (not useful heat in this example, for the sake of brevity), there are several possible ways of approaching the displacement calculation.

For instance, a power station operating continuously might use the grid average emission factor as a basis for comparison. A power station designed to ramp generation up or down in response to supply and demand signals might work to a weighted average short-run marginal emission factor associated with its operating profile: this is a more complex analysis as the marginal generator will sometimes be low carbon itself (for instance, thermal generators are often turned down to maximise the use of available wind and solar energy), and sometimes much more carbon intensive (e.g. when banks of diesel generators join the grid to meet peak demand). And a new power station would have a case for using a long-run marginal factor, based on what the likely alternative for that power station would be: in some cases it can be justifiable to compare it to older, inefficient coal power plant extending its operating life, but in jurisdictions where such plant is already becoming obsolete it can be more appropriate to compare either with an up-to-date alternative such as a combined cycle gas turbine generator, or even with a blended alternative based on where (in the power sector) the investment would otherwise be directed. In practice, many cases will not fit neatly into such categories, and the best way forward is simply to state the choice made and the reasons for making it.

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