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Wood and wood-based products — Background and examples of calculating contributions to carbon stored in harvested wood products (HWP)

Bois et produits à base de bois — Contexte et exemples de calcul des contributions au carbone stocké dans les produits ligneux récoltés (PLR)

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Contents

Page

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. The framework identifies a component for wood-based carbon (i.e. biogenic carbon stored in wood-based products), representing the contributions to the harvested wood products (HWP) pool and wood-based carbon storage in landfills or through biogenic carbon capture and storage (bio-CCS), see Figure 1. ISO 13391-1 further elaborates on the calculation of these contributions based on the delivery of a set of wood and wood-based products in a specified time period at an organizational or aggregate level. This document provides additional background and examples to users of ISO 13391-1.

ISO 13391-1 introduces the concept of a HWP coefficient to estimate the long-term contribution of a set of wood and wood-based products to the HWP pool. It is defined as a factor for calculating the net contribution to the HWP pool per delivered volume of a wood-based product. Subclause 5.4 of that document elaborates on the calculation of HWP coefficients.

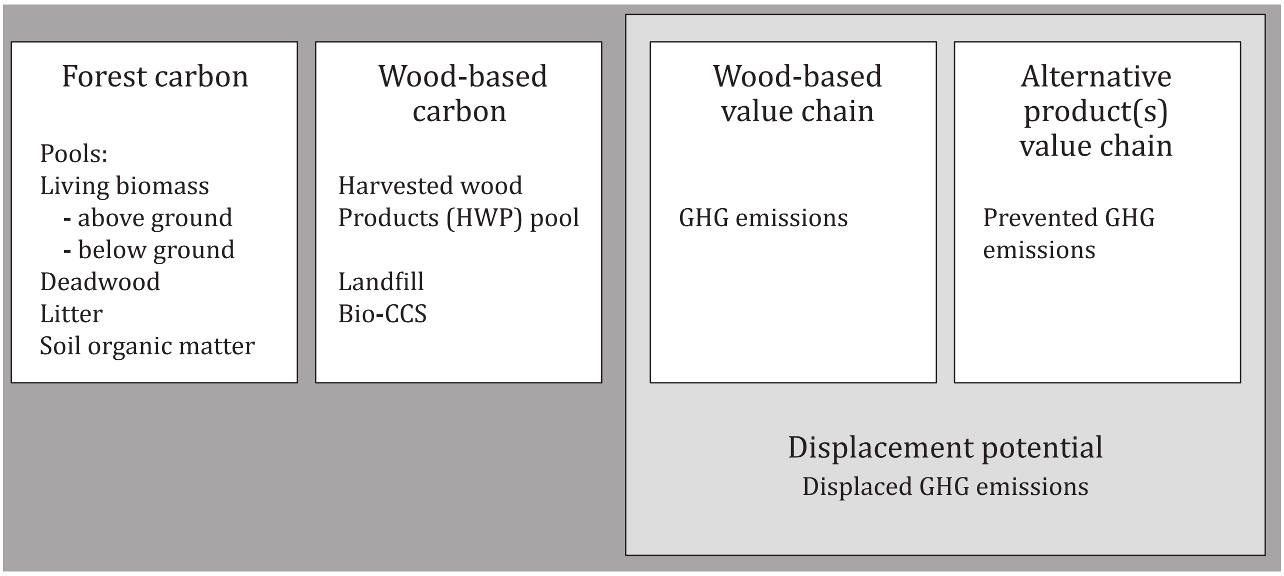


Figure 1 — Illustration of the components of the greenhouse gas dynamics of wood and wood-based products

This document provides background and examples. Clause 4 introduces the concept of an HWP coefficient, as used in ISO 13391-1. Clause 5 considers the background to quantification of HWP storage, with particular relevance to the IPCC methodologies used for national reporting.

Clause 6 considers the data requirements for calculating HWP coefficients and provides examples of HWP coefficients, according to the tier 1 methodology of ISO 13391-1. These include factors for recycling.

This is followed by Clause 7, in which the details of calculating HWP coefficients are considered, when working from market data and models. The concept of handling recycling within HWP coefficient calculations is introduced. It also considers the other methodologies for HWP calculations, as discussed in the IPCC guidelines, often termed tier 2 and tier 3 methods, and their counterparts within ISO 13391-1. This provides context for ongoing research activity and thought leadership in the field, which is evolving.

Clause 8 provides a literature review showing how research has progressed on this topic.

Clause 9 gives examples of methods for calculating an HWP coefficient using national inventory reports, market development data or organization-specific data. It also details some sensitivities related to these examples.

Clause 10 discusses the long-term storage of carbon in wood and wood-based products which are disposed into landfill, or into other long term storage options including bio-CCS, biochar etc.

NOTE The methods described in this report are largely based on IPCC guidelines; however, approaches for organizational or national reporting can vary depending on local conditions or legislations.

Wood and wood-based products — Background and examples of calculating contributions to carbon stored in harvested wood products (HWP)

1 Scope

This document provides background information, methods and examples of calculating contributions to carbon stored in wood-based products (harvested wood products, HWP), including storage resulting from HWPs in landfill and bio-CCS, as defined in ISO 13391-1:2025. It includes background to the tier 1 HWP coefficients for various wood-based product categories defined in ISO 13391-1:2025.

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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13391-1 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 The harvested wood product coefficient (HWP coefficient) concept

Wood-based products in use, including the use of recycled wood-based material, extend the time of biogenic carbon storage until the material is disposed of, after which the wood-based carbon is released to the atmosphere, enters landfills, or meets a different fate. The carbon storage in wood-based products is therefore considered as a carbon pool by IPCC, as described in Clause 5.

The pool of carbon in wood-based products (or harvested wood products - HWP) has an inflow of new woody material, and an outflow of disposed woody material. The difference between the inflow and outflow in a given time period represents the net change in the HWP pool.

The HWP coefficient has been defined in ISO 13391-1 as the proportion of the inflow that represents a net change in the HWP pool. This builds on the principle that it is the net change of the HWP pool that is relevant for the greenhouse gas dynamics, just as the net change of forest carbon storage is relevant.

While the inflow of new material is straightforward to calculate based on the quantities of wood-based products put on the market by an organization, the outflow depends on the quantities and fates of corresponding products put on the market historically. Determining the outflow from the pool related to the organization’s production is therefore a critical methodological aspect. As the actual outflow is difficult to measure, this can be done through modelling.

Two main parameters for determining the outflow through modelling are:

a) The rate of decay of woody material in the HWP pool. This is usually determined by assuming an estimated life span for each product category, combined with assumptions on proportions of recycling.

b) The historical growth or decline of market quantities for each product category.

Over the long term, an increasing market quantity will increase the HWP pool and thereby result in a positive HWP coefficient, while a decreasing market will lead to a decrease of the HWP pool and a negative HWP coefficient. However, as it is not meaningful to assign a negative storage effect for an organization that delivers products, which are physically storing carbon, to the market, ISO 13391-1 states that the HWP coefficient can be assumed to be zero in this case.

One limitation of this approach is that the calculation of HWP coefficients to be applied by an organization will depend on products delivered in the past, whose fate the organization cannot influence.

Another limitation is that historical market developments can vary between regions, which can lead to different HWP coefficients for similar products.

The HWP coefficient is used to estimate the present net gain of carbon in the HWP pool, but it does not indicate a permanent net gain.

The following clauses elaborate on the use of HWP coefficients when implementing ISO 13391-1.

5 Background and options provided by IPCC Guidelines and their applicability for reporting at an organizational level

5.1 General

The methodology to estimate the carbon storage associated with a HWP carbon pool in ISO 13391-1 is based on the 2019 Refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories,[6] adjusted for use at an organizational or aggregate level.

5.2 explains the guidance provided by IPCC,[6] as background for calculating the contribution to the HWP pool according to ISO 13391-1. In order to calculate the carbon storage in the HWP pool under the IPCC Guidelines, both an approach and a method need to be defined. The approaches and methods outlined in the IPCC Guidelines are described in the following clauses.

5.2 HWP approaches to estimate greenhouse gas dynamics

5.2.1 Approaches

The IPCC Guidelines define different ‘approaches’ that can be taken to estimate greenhouse gas dynamics of a HWP pool. The approach defines the system boundary, which indicates what will be estimated and reported when calculating the greenhouse gas emissions and removals of an HWP. The approach is defined to ensure that all emissions and removals are accounted for and double-counting does not occur, by being transparent, complete, and consistent. When selecting the approach, it is important to consider the specific question being addressed or the type of estimate that is required.

The 2006 IPCC Guidelines[8] consider four approaches for calculating the greenhouse gas emissions and removals of an HWP:

— ‘stock-change’ approach which estimates changes in carbon stocks in the HWP pool within the national boundaries;

— ‘production’ approach which estimates changes in carbon stocks in the HWP pool consisting of products made from wood harvested in a country;

— ‘atmospheric-flow’ approach which estimates fluxes of greenhouse gases from and to the atmosphere from HWP, taking place within national boundaries; and

— ‘simple-decay’ approach which estimates fluxes of greenhouse gases from and to the atmosphere from HWP, associated with woody biomass harvested from the forests and other wood-producing lands within a country.

The four IPCC approaches have similarities and differences based on what is being estimated and where the HWP is being consumed and used. As per the guidelines:

— The ‘stock-change’ and ‘production’ approaches work with carbon stock changes in HWP pools, whereas the ‘atmospheric-flow’ and ‘simple-decay’ approaches work with greenhouse gas fluxes;

— The ‘stock-change’ and ‘atmospheric-flow’ approaches cover stock changes or greenhouse gas fluxes associated within a consuming country, whereas the ‘production’ and ‘simple-decay’ approaches cover those associated with a producing country.

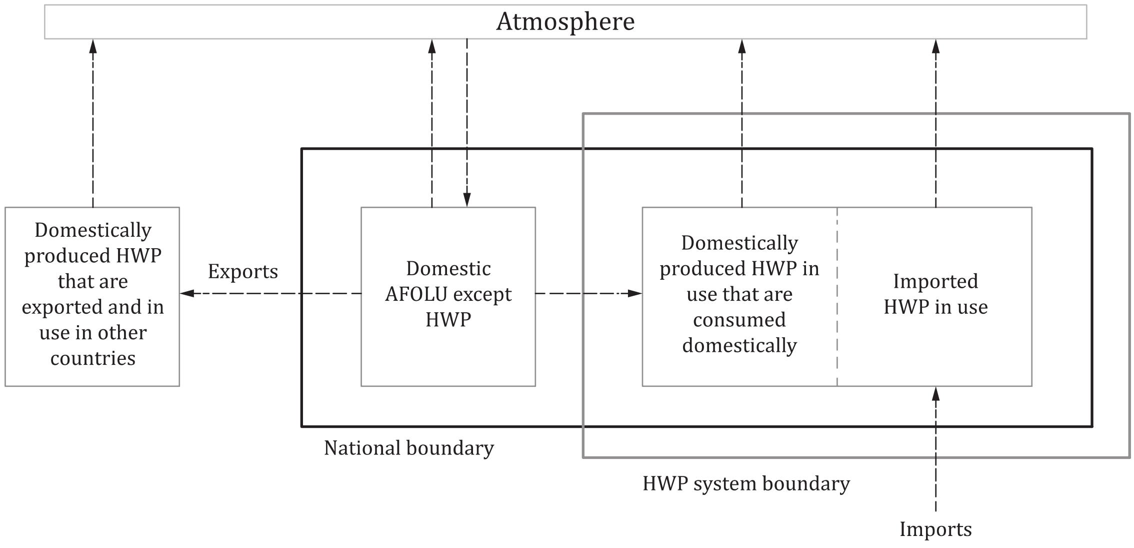
In the context of organizational greenhouse gas dynamics (considered in ISO 13391-1) the production approach is of greatest relevance. Organizations might find the principles of other approaches useful in other contexts, depending on their location within the supply chain and other factors.

The following subclauses describe in further detail the differences in the system boundaries of the various IPCC approaches in order to estimate the greenhouse gas dynamics.

5.2.2 Estimating greenhouse gas dynamics based on carbon stock changes

The two IPCC approaches to estimate the greenhouse gas emissions and removals associated with a HWP based on the carbon stock changes in the biomass pools are the ‘stock-change’ approach and ‘production’ approach.

The two pool-based approaches contain conceptual differences which impact the carbon inflow to the HWP pool. For instance, the annual carbon inflow to the HWP pool based on the ‘stock change approach’ is calculated based on the domestic consumption, while the ‘production’ approach is calculated based on the domestic production. Since the ‘stock change’ approach estimates carbon stock changes of a HWP in use within national boundaries, the calculated domestic consumption accounts for domestic production, plus imports and minus exports of HWP in use that are consumed domestically. Domestically produced HWP that are exported and in use in other countries are outside of the system boundary. Therefore, the HWP pool system boundary for the ‘stock change’ approach is within the national boundary, as shown in Figure 2.



NOTE AFOLU stands for Agriculture, Forestry and Other Land Use.

Figure 2 — System boundary of the ‘stock change’ approach[6]

On the other hand, since the ‘production’ approach estimates carbon stock changes of ‘products in use’, the annual carbon inflow to the HWP pool accounts for the domestic production of wood commodities manufactured from domestic harvest. Therefore, domestically produced HWPs that are exported and in use in other countries are within the system boundary. As a result, the HWP pool system boundary for the ‘production’ approach does not align with the national boundary, as shown in Figure 3.

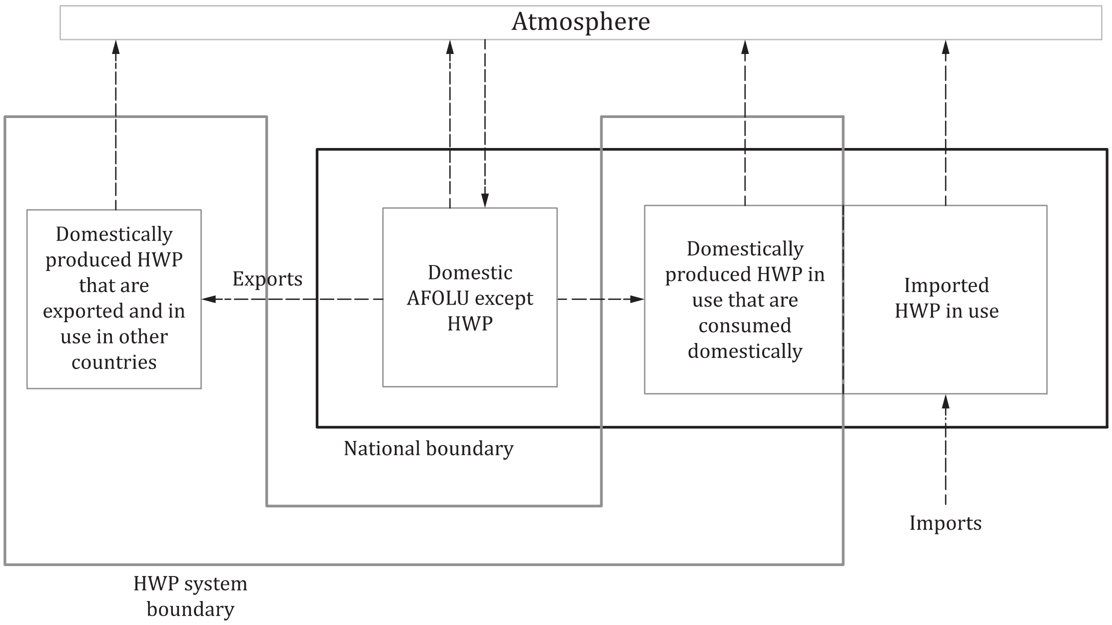
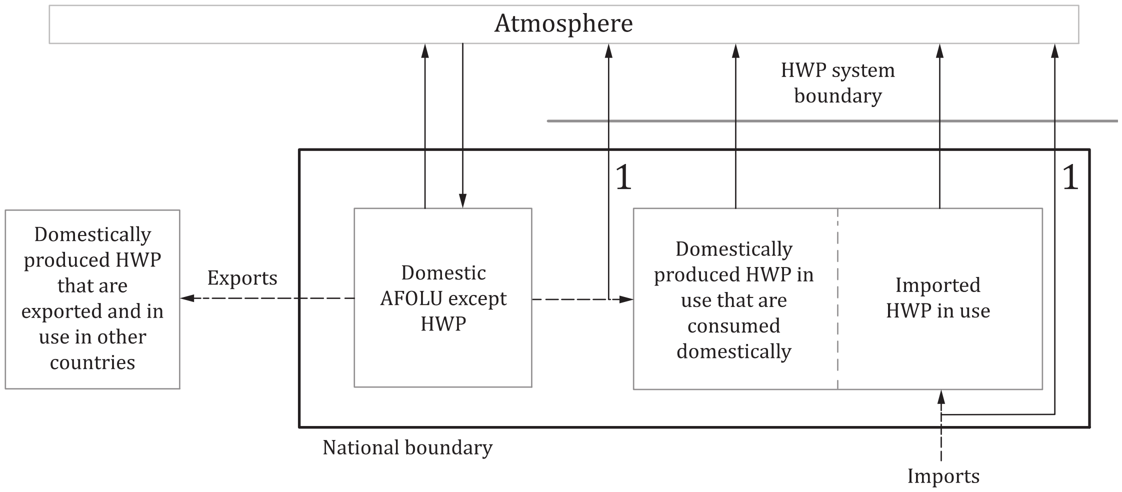


Figure 3 — System boundary of the ‘production’ approach[6]

5.2.3 Estimating greenhouse gas dynamics based on greenhouse gas fluxes to the atmosphere

The two approaches to estimate the greenhouse gas emissions and removals associated with a HWP based on greenhouse gas fluxes to the atmosphere are the ‘atmospheric-flow’ approach and ‘simple-decay’ approach.

The two greenhouse gas flux-based approaches consider both carbon stock changes within the HWP pool in use, as well as all cross-border greenhouse gas fluxes in wood-based products used for energy. Since the ‘atmospheric-flow’ approach considers greenhouse gas fluxes occurring within national boundaries, the emissions from HWP and wood-based products used for energy are reported by a consuming country. In this approach, the HWP pools are the same as the ‘stock-change’ approach. The HWP pool system boundary for the ‘atmospheric-flow’ approach is shown in Figure 4.

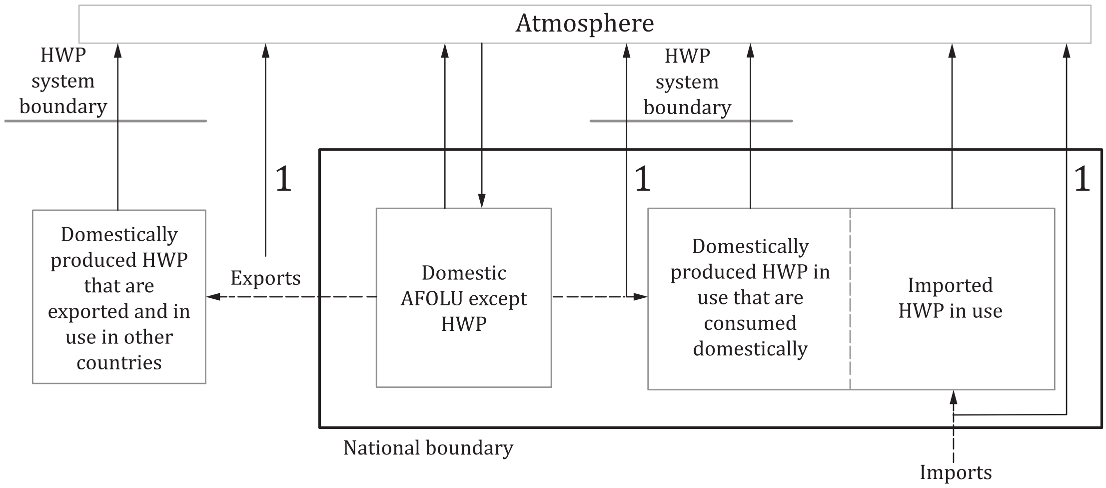


Key

1 Conceptually, the atmospheric-flow approach is based on tracking all CO_2 fluxes across the HWP system boundary. Hence, fluxes associated with wood feedstocks directly used for energy purposes are included.

Figure 4 — System boundary of the 'atmospheric-flow' approach[6]

On the other hand, the 'simple-decay' approach considers greenhouse gas fluxes arising from wood harvested by a producing country. As such, the HWP pool system boundary includes domestically produced HWPs and wood-based products used for energy that are in use and domestically consumed, as well as exported and in use in other countries. The HWP pool system boundary for the 'simple-decay' approach is shown in Figure 5.



Key

1 Conceptually, the simple-decay approach is based on tracking all CO_2 fluxes across the HWP system boundary. Hence, fluxes associated with wood feedstocks directly used for energy purposes are included.

Figure 5 — System boundary of the 'simple-decay' approach[6]

5.3 HWP methods to estimate greenhouse gas dynamics

In addition to defining the approach, the method for estimating greenhouse gas emissions and removals associated with the HWP is also selected to determine how the inventory is going to be calculated. Methods are divided into three tiers, with tier 1 providing a basic method and tier 3 being the most demanding in terms of complexity and data requirements. The choice of the method depends on the availability of activity data on HWPs (wood and wood-based products production, imports, and exports), availability of country-specific data, and the availability of country-specific methods. The IPCC Guidelines[6] suggest that it is good practice to follow the decision tree in Figure 6 for selecting the relevant tier method for estimating greenhouse gas emissions and removals arising from HWPs.

The IPCC 2019 refinement to the 2006 Guidelines[6] refers to several different methods within the different tiers. For instance, if no activity data is available, the ‘steady state HWP pool’ assumption can be applied. However, the most commonly used method is the first order decay method, which is the foundation of the tier 1 methodology. First order decay is also permitted within tier 2 and 3. Lastly, flux data methods and stock inventory data methods are also available to be used within tier 3. These methods will be further described in later clauses.

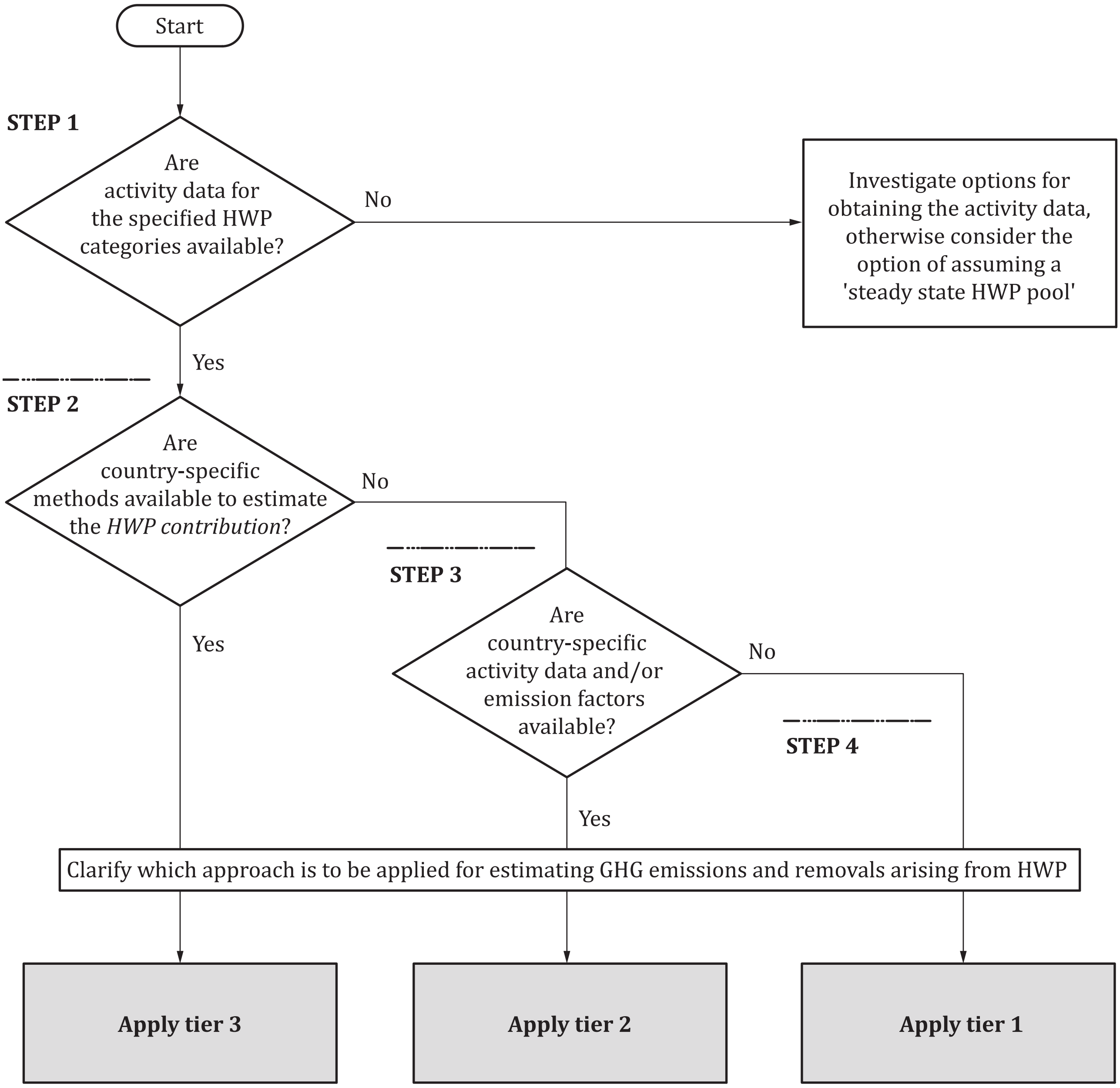


Figure 6 — Decision tree for choosing the relevant tier method for estimating greenhouse gas emissions arising from HWP[6]

Two main commodity class types are referenced in the IPCC Guidelines: semi-finished products and finished products. Semi-finished products, sometimes referred to as primary products, are materials used to make finished products. The default semi-finished commodity classes in the IPCC Guidelines and ISO 13391-1 are sawn wood, wood-based panels, and paper and paperboard. Finished products, sometimes referred to as secondary products, are product end uses, such as buildings, furniture, or books. At minimum, activity data for the three default semi-finished HWP commodity classes of sawn wood, wood-based panels, and paper and paperboard, is required for tier 1 as per the IPCC Guidelines where the first-order decay method is applied (further described in Clause 6). However, ISO 13391-1 also covers wood-based products used for energy and roundwood in the tier 1 method. If relevant activity data is available in public databases of international organizations, such as FAOSTAT (the statistical databases of the Food and Agriculture Organization of the United Nations), then the data is suitable for tier 1 and tier 2 methods. Activity data for the HWP is typically reported in cubic metres solid volume or metric tonnes, which can be converted into units of biogenic carbon.

The tier 2 method, as per IPCC guidelines,[6] can be applied when country-specific activity data or emission factors (e.g. based on ISO 15686-1 categories of product and service life) is available for the three default HWP commodity classes. Additionally, the tier 3 method can be applied when both country-specific activity data and methods are available to calculate the HWP pool. Tier 3 allows finished products to be handled, or to use flux data methods to estimate or model HWP pool changes, or to use direct inventory for some aspects (e.g. HWPs in housing stock or structures). Tier 2 and tier 3 methods are further described in Clause 7.

If there is no information on the utilization of the HWP commodity classes, then countries using the IPCC Guidelines[6] can consider making an assumption of a ‘steady-state HWP pool’. As per IPCC Guidelines,[6] this assumes that “annual inflows into HWP in use are exactly the same in magnitude as the annual losses of carbon from HWP in use”. Therefore, although the carbon stock of the HWP is not zero, it is not changing over time. At the organizational level, the same considerations apply, but if the absence of information applies to all the commodity classes handled by the organization, then it would be more realistic to report this fact rather than to assume and report a steady-state result.

5.4 IPCC tiers 2 and 3 calculations

The IPCC guidelines[6] allow a tier 2 or a tier 3 method to be used where suitable additional data is available, as shown in Figure 6. These tiers broadly reflect the approach taken in ISO 13391-1:2025, but with some variations which are described in below.

The IPCC[6] tier 2 method is country-specific and an option within it considers product categories defined in ISO 15686-1, where the service lives of the product categories are used to calculate the half-life. These categories allow for a more differentiated set of products in the assessment but exclude finished products (which are addressed in IPCC tier 3). A similar approach is assumed at an organizational level in tier 2 of ISO 13391-1, which is considered in greater detail in 7.4.1 and 7.4.2.

6 Tier 1 calculations

6.1 General

ISO 13391-1 and the IPCC guidelines[6] share common features with regards to tier 1 processes, including product categories and half-lives considered.

In 6.2 we consider the fundamentals of IPCC tier 1. 6.3 and 6.4 bridge into the use of HWP coefficients to consider tier 1 situations. 6.5 provides examples of tier 1 HWP coefficients.

6.2 First order decay in IPCC tier 1

The IPCC tier 1 method is applied when activity data is available for the broad product category HWP commodity classes (sawn wood, wood-based panels, paper and paperboard). The IPCC Guidelines[6] provide tier 1 default methods relevant for implementing the four HWP approaches defined in 5.2, where the first-order decay (FOD) function is used to estimate the carbon stock at the beginning of a year, as well as the annual carbon stock changes in the HWP.

First-order decay function is given by Formula (1):

$$C_{\mathrm{l}}(i+1) = \mathrm{e}^{-k} \times C_{\mathrm{l}}(i) + \left[\frac{\left(1-\mathrm{e}^{-k}\right)}{k}\right] \times m_{\mathrm{C,l}(i),\mathrm{in}}$$
$$\Delta C_{\mathrm{l}}(i) = C_{\mathrm{l}}(i+1) - C_{\mathrm{l}}(i) \tag{1}$$

where

i	is the year;
$C_{\mathrm{l}}(i)$	is the the carbon stock in the particular HWP commodity class l at the beginning of the year i (Mt C);
k	is the decay constant of FOD for each HWP commodity class l given in units y^{-1} (=ln(2)/HL, where HL is the half-life of the particular HWP commodity in the HWP in years);
$m_{\mathrm{C,l}(i),\mathrm{in}}$	is the the carbon inflow to the particular HWP commodity class l during the year i (Mt C y^{-1});
$\Delta C_{\mathrm{l}}(i)$	is the carbon stock change of the HWP commodity class l during the year i (Mt C y^{-1}).

The decay constant (k) is expressed as half-life in years, which is defined in the 2006 IPCC Guidelines[8] as “the number of years it takes to lose one half of the material currently in the pool”. When applying the tier 1 method, the IPCC Guidelines[6] provide default half-lives for the three default HWP commodity classes: 35 years for sawn wood, 25 years for wood-based panels, and 2 years for paper and paperboard.

The default IPCC half-lives for tier 1 relate to the whole range of products within that category, which works well for national level reporting. However, difficulties can arise when working at an organizational level. The default IPCC half-life values can lead to distorted results if applied to very narrow product groups, for example if an organization has a very limited product range, with a lifespan that is either much lower or much higher than the population average for the broader category. For example, if a sawmill produces only pallets, (i.e. a subcategory of solid wood), the half-life of 35 years can considerably overestimate the HWP effect of their product range. However, as the aim of the methodology in ISO 13391-1 is to provide an achievable tier 1 methodology, these biases cannot be fully mitigated.

The tier 1 default method using the ‘production approach’ was used to develop the HWP coefficients introduced and discussed below.

6.3 Data requirements to calculate HWP coefficients in ISO 13391-1

ISO 13391-1 uses HWP coefficients to express the proportion of carbon contained in wood-based product(s), delivered to the market in a specified time period, that represent a net increase of the HWP carbon pool in society.

Determining the HWP coefficient for a product category requires data on

a) inflow: the quantity of wood-based carbon of the product category entering the HWP pool in the specified time period, and

b) outflow: the quantity of wood-based carbon related to the product category exiting the HWP pool.

NOTE This applies also to tier 2 and 3. Formula 2 has been used to generate the tier 1 HWP coefficients.

Based on ISO 13391-1, the HWP coefficient is calculated as given by Formula (2):

$$k_{\mathrm{HWP}} = \frac{w_{\mathrm{C,HWP,in}} - w_{\mathrm{C,HWP,out}}}{w_{\mathrm{C,HWP,in}}} \tag{2}$$

where

k_{HWP} is the HWP coefficient, expressed as the proportion of net contribution to the HWP carbon pool in the specified time period;

$w_{\mathrm{C,HWP,in}}$ is the inflow of biogenic carbon from the volumes of wood and wood-based products placed on the market in the specified time period, expressed in t CO_2e;

$w_{\mathrm{C,HWP,out}}$ is the outflow of biogenic carbon from the HWP carbon pool from corresponding wood and wood-based products reaching end of life, after the last recycling round, in the specified time period, expressed in t CO_2e.

This follows the "production approach" in the IPCC Guidelines,[6] which is used to report at the national level. The IPCC method takes the perspective that the producing country accounts for the increase or decrease of the downstream HWP pool, as described in Clause 5. Similarly, ISO 13391-1 takes the perspective that an organization producing and putting wood-based products on the market accounts for downstream changes in the HWP pool related to its delivered volumes.

Based on ISO 13391-1, the HWP pool contribution by an organization in a specified time period is then calculated as given by Formula (3):

$$\Delta w_{\mathrm{C,HWP}} = \sum\nolimits_{1}^{i} (w_{\mathrm{B},i} \times k_{\mathrm{HWP},i}) \tag{3}$$

where

$\Delta w_{\mathrm{C,HWP}}$ is the HWP carbon pool change resulting from an organization placing wood and wood-based products on the market in the specified time period, expressed in t CO_2e;

$1 \ldots i$ are the product categories included;

$w_{\mathrm{B},i}$ is the quantity of biogenic carbon in the woody material of product *i* placed on the market in the specified time period , expressed in t CO_2e;

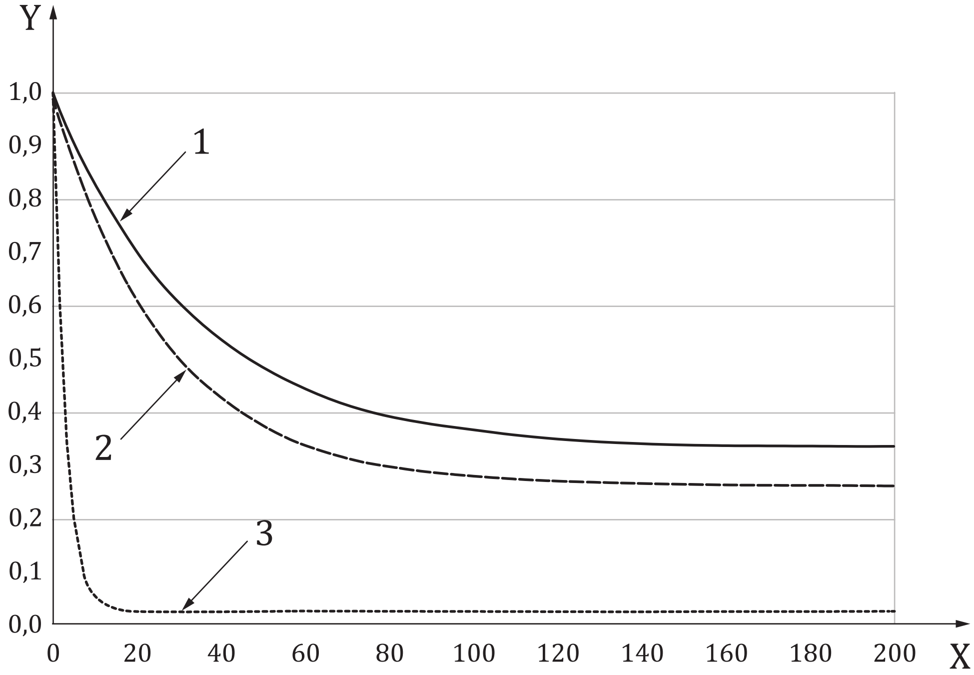
$k_{\mathrm{HWP},i}$ is the HWP coefficient for product category *i*.

The data requirement on wood-based carbon entering the HWP pool (inflow) for a product category is often straightforwardly met. It is calculated based on the quantity of wood-based carbon in delivered products during the specified time period, considering the market growth in that time and outflows from previous time periods. It is also possible to include the proportion of outflow from the previous time period that is recycled, as discussed in Clause 7.

Determining the quantity of corresponding wood-based carbon exiting the HWP pool (outflow) in the specified time period is a bigger challenge for the organization, requiring more data, see discussion of Tier 2 and Tier 3 methods in Clause 7. Within Tier 1, the default IPCC half-lives for sawn wood, wood-based panels and paperboard are used. Clause 10 provides examples that can be applied.

6.4 Using HWP coefficients in the first order decay model in ISO 13391-1

Using the half-lives to plot a residence time, it is possible to model HWP retention. From this a HWP coefficient can be calculated based on HWP inflow and HWP outflow. The graph below was generated using a 1 % market growth factor year on year (which was selected to be representative for the wood-based product sector as a whole, based on FAO annual statistics). The HWP coefficient on the y-axis is determined using the net quantity entering the pool (carbon stock change of the HWP pool during a specific year) divided by the total inflow, thus in early years the value is high, but as the pool size grows, and the quantity exiting the pool from previous years increases, it follows an exponential trend, tending towards a horizontal state at long durations, see Figure 7.



Key

X number of years

Y HWP coefficient

1 HWP coefficient as modelled over time for sawn wood (half-life 35 years)

2 HWP coefficient as modelled over time for wood-based panels (half-life 25 years)

3 HWP coefficient as modelled over time for paper and paperboard (half-life 2 years)

Figure 7 — Simulation results for HWP coefficients with initial pool size zero

The products with a short half-life (line 3) tend towards a horizontal line earlier than the products with higher half-lives.

From this graph it is possible to determine a coefficient at the suitable time point where the line is considered effectively horizontal. This portion of the curve reflects the flux of product into and out of an established market, such as sawn wood.

The coefficient therefore reflects the long-term net addition to that pool as a function of market growth. As market growth projections from further back in time are included in the calculation, the coefficient reaches an asymptote. The asymptote occurs when the amount of carbon leaving the HWP pool each year from the products of interest is proportional to the carbon leaving the HWP pool from the historical products. The coefficient calculated at the asymptote is therefore the most representative of the long-term net addition of HWPs to the pool. In the case of product categories with long half-lives or high recycling rates, it is necessary to include past market growth over a long time period to reach an asymptote. It is therefore recommended that the modelling expands back as long as necessary (e.g. 200 years) for the HWP coefficient to reach an asymptote. Assuming a 1 % growth rate for the past 200 years, the coefficients are calculated as follows: 0,33 for sawn wood with a half-life of 35 years, 0,26 for wood-based panels with a half-life of 25 years and 0,02 for paper and paperboard with a half-life of 2 years assuming no recycling.

When combined with quantities of the organization’s material placed on the market in a given time period the coefficient can give a reasonable estimate of the HWP carbon which will remain in storage in the long term. Note that in later clauses of this document 200 years will be used to represent the point at which time tends towards infinity and the HWP coefficient value stabilises.

In Clause 7 several effects which have an influence on the HWP storage are discussed further. These include the potential to select different half-lives (which is a tier 2 method), or to include recycling within the model. Recycling is well established in many regions, and recycling rates are often available for wood-based products. Therefore ISO 13391-1 has developed a novel way of accounting for recycled wood or fibrous material that remains within the product category. This is discussed in Clause 7.

Other half-lives that are region-specific or product-specific could be considered where more data is available at the relevant level. This makes it possible to apply either a tier 2 or tier 3 method to calculate an organizational half-life, as discussed in 5.4 and 7.4.

In addition, the market growth will influence the HWP coefficient, and this is considered in a sensitivity analysis in 9.5. Example 2 in 9.3 discusses whether a linear or a compound growth rate is appropriate for typical HWP markets.

6.5 Tier 1 HWP coefficients

Based on Clauses 6 and 9, the examples of HWP coefficient at tier 1 level can be considered as per Table 1. The inflow to the HWP pool is the product quantity delivered in the specified time period. The modelled value for roundwood in Table 1 is explained in 7.3. In Table 1 the value for roundwood relates to 30 % solid wood, and 30 % recycling of paper and paperboard. Other options are considered in Table 4.

The modelled values in Table 1 for sawn wood, wood-based panels and roundwood appear to be supported by the Swedish national inventory reports (Figure 10, Example 1B). The reported values for Swedish paper and paperboard however appear to be considerably higher than the modelled value.

In Table 1 a 30 % recycling rate has been assumed within the modelling of HWP value for paper and paperboard. The approach for modelling recycling, and the use of different recycling rates are explained and considered in 6.2. Bioenergy products are considered to not generate any HWP pool as they are oxidized soon after production, meaning the HWP coefficient is 0.

Table 1 — Tier 1 HWP coefficients based on results in Clauses 5 and 6

Product category	Tier 1 HWP coefficient
Industrial roundwood	0,1
Sawn wood (35 years half-life)	0,33
Wood-based panels (25 years half-life)	0,26
Paper and paperboard (2 years half-life and 30 % recycling)	0,04
Bioenergy products	0

NOTE The default IPCC half-life values can lead to distorted results if applied to very narrow product groups. Where a mill knows they have a narrow product range a suitable alternative half-life can be selected to better reflect the lifespan of these products within a Tier 2 methodology, see 7.4.

Clause 9 provides examples on variations in the HWP coefficient depending on assumptions and contexts that can be considered as alternatives.

Finally, the IPCC[6] tier 3 method contains several methods, one of which allows finished products to be handled within a first-order decay model. Other options include the use of flux data methods to estimate or model HWP pool changes, or to use direct inventory for some aspects (e.g. HWPs in housing stock or structures). These aspects are considered in greater detail in 7.4.3.

7 Calculation of HWP contribution under tiers 2 and 3

7.1 General

ISO 13391-1 tier 2 allows the HWP coefficient to be estimated for a more differentiated or specific set of wood-based products where data is available. Examples of data requirements for a product category include:

— half-life (years);

— recycling rates (%);

— market development rate (% per year);

— roundwood utilization rates (% by volume).

Half-life indicates the decay rate as elaborated in Clause 6. For the purpose of modelling described in this clause, any half-life can be assumed and results are provided for the range 2 years to 50 years in Table 2. A spreadsheet with HWP coefficient calculations is also available, allowing user-selected values for half-life and other parameters. This spreadsheet is named “Spreadsheet HWP coefficient model” and is available at: https://standards.iso.org/iso/tr/25080/ed-1/en.

Tier 2 also allows other methods for modelling decay besides first order decay, as well as other methods for estimating the greenhouse gas dynamics of temporary storage and delayed greenhouse gas emissions, where appropriate. The HWP contribution can be directly calculated under tier 3 when primary data for both inflow and outflow is available.

7.2 Recycling rates and market growth

Recycling rates refer to the proportion (0 % to 100 %) of wood-based material that is recycled into subsequent products, thereby extending the time of carbon storage for this fraction. Model results are provided for the range 0 % to 90 % recycling in Table 3.

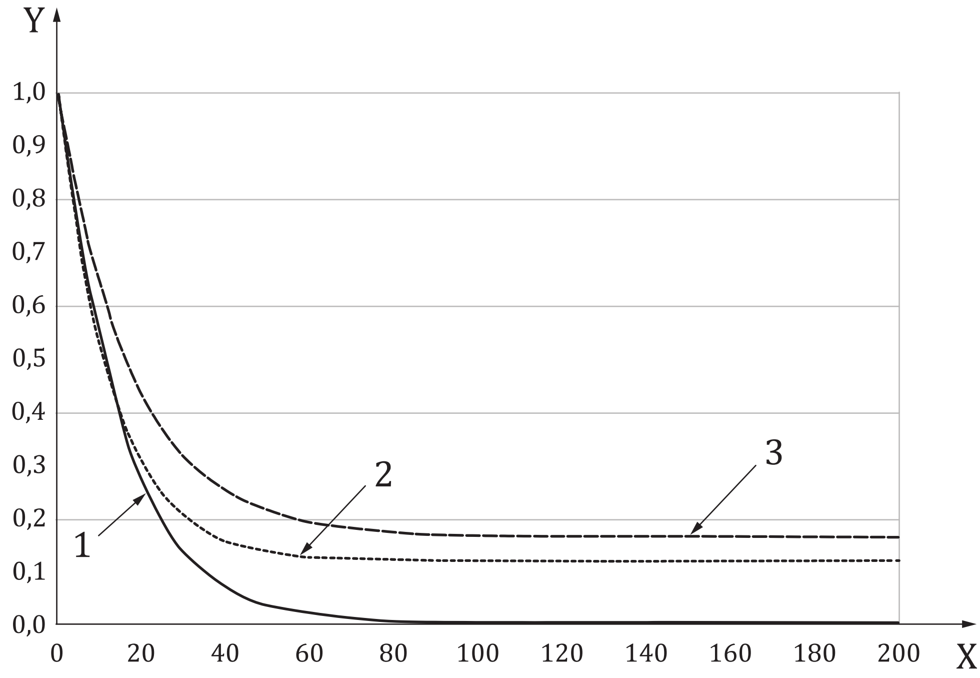
Market development rate indicates the long-term volume growth of the market, based on historical data as elaborated in 9.3. For the model results presented below, a compound growth rate of 1 % has been used which is lower than actual world market developments (Table 2). Modelling can assume different growth rates, or use linear instead of compound growth, which will lead to different results.

The value sought is the proportion of a delivered volume of the product category in a given year that represents an increase (or decrease) to the overall HWP pool. Calculating this requires that the current decay rate of the pool is known, which in turn requires historical information on past delivery volumes of the product category over time, and the calculated remaining carbon pool of these deliveries.

The IPCC first order decay function (see Clause 6) can be applied for the purpose by simulating a long (200 years) time series. The market inflow in year 200 ($w_{\mathrm{C,HWP,in,year\,200}}$) is determined by the inflows of (a) the market growth over time, and (b) the proportion of the outflow from the previous year that is recycled, where the first order decay function is applied. An initial carbon pool of zero grows over time as each year’s products enter the market, but as the pool stabilises and material exiting the pool is modelled using a half-life (simple decay) function, the annual flux becomes stable, approaching the asymptote. This allows a HWP coefficient to be plotted, as shown in 6.4, Figure 7. An approximate HWP coefficient can then be established against this asymptote as given by Formula (4):

$$k_{\mathrm{HWP}} = \frac{w_{\mathrm{C,HWP,in,year\,200}} - w_{\mathrm{C,HWP,out,year\,200}}}{w_{\mathrm{C,HWP,in,year\,200}}} \qquad (4)$$

Example values of modelled HWP coefficients are shown in Figure 8, for half-life of 10 years with varying market growth and recycling rates. All three examples in Figure 8 use half-life of 10 years. Market volume increase is set to 0 (example 1), and 1 % per year (example 2, example 3). Recycling rates are set to 0 (example 1, example 2) and 30 % (example 3). Indicated HWP coefficient asymptotes are 0,00; 0,12 and 0,17 respectively. An excel model for the purpose is made available as a supplement to this technical report, which is named “Spreadsheet HWP coefficient model” and is available at: https://standards.iso.org/iso/tr/25080/ed-1/en.



Key

X number of years

Y HWP coefficient

1 Example 1, see Table 2 for data.

2 Example 2, see Table 2 for data.

3 Example 3, see Table 2 for data.

NOTE See Table 2 for the data behind the three lines.

Figure 8 — Results of HWP coefficient modelling over 200 years using different recycling rates and market growth values

Table 2 — Values used in Figure 8 for modelling the HWP coefficient asymptotic value

	Example 1	Example 2	Example 3
Initial pool size	0	0	0
Half-life	10 years	10 years	10 years
Recycling rate	0	0	30 %
Market growth	0	1 % per year	1 % per year
Pool size at year 200	14	88	119
HWP coefficient at year 200	0	0,12	0,17

Applying a market volume increase of 1 % per year (justified by above historical data, see 9.3), leads to results from the model approach for different combinations of half-life and recycling rates as per Table 3.

Table 3 — HWP coefficient model results assuming a market volume increase of 1 % per year for different combinations of half-life and recycling rates

Half-life years	**Recycling rate** %									
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
2	0,02	0,03	0,03	**0,04**	0,04	0,05	0,07	0,09	0,14	0,25
5	0,06	0,07	0,08	0,09	0,11	0,13	0,15	0,20	0,27	0,44
10	0,12	0,13	0,15	0,17	0,19	0,22	0,27	0,33	0,43	0,61
15	0,17	0,19	0,21	0,23	0,26	0,30	0,35	0,42	0,53	0,70
20	0,22	0,24	0,26	0,29	0,32	0,37	0,42	0,50	0,61	0,76
25	**0,26**	0,28	0,31	0,34	0,38	0,42	0,48	0,56	0,66	0,80
30	0,30	0,32	0,35	0,38	0,42	0,47	0,53	0,60	0,70	0,83
35	**0,33**	0,36	0,39	0,42	0,46	0,51	0,57	0,64	0,73	0,85
40	0,36	0,39	0,42	0,46	0,50	0,54	0,60	0,67	0,76	0,87
45	0,39	0,42	0,45	0,49	0,53	0,58	0,63	0,70	0,78	0,88
50	0,42	0,45	0,48	0,51	0,56	0,60	0,66	0,72	0,80	0,89

NOTE IPCC Guidelines for HWP calculations[6] recommend 35 years half-life for sawn wood, 25 years for wood-based panels and 2 years for paper and paperboard. These cases have been marked in bold font, with the assumption of a 30 % recycling rate for paper and paperboard.

7.3 HWP coefficient for roundwood

Depending on tree sizes at harvest and the characteristics of the wood-based value chain, roundwood will be used differently, with different fractions going to solid wood products or paper and paperboard. Table 4 applies results in Table 3 to infer HWP coefficient for roundwood under different circumstances. The rows and columns represent different percentages of carbon that end up in solid wood and fibre-based products, respectively. This includes the use of mill residue (e.g. wood chips used in the production of fibre-based products). The sum of these percentages can be less than 100 % because of energy generation and other uses where no storage occurs. In Table 4, the solid wood category is assumed to be 50 % sawn wood and 50 % wood-based panels. For fibre-based products, a two-year half-life and 30 % recycling rate was assumed. Any percentage not covered in the Table 4 is assumed to be waste or used for energy with no HWP storage effect.

NOTE Over the last 2 decades, global paper recycling rates have increased from around 47,6 % in 2001 to 59,9 % in 2021.[16] Regional recycling rates and rates in different categories of paper vary.

Table 4 — HWP coefficient for roundwood calculated based on data in Table 3 under scenarios where different fractions of the roundwood falls into solid wood products and paper and paperboard respectively

Solid wood %	**Fibre-based products (30 % recycling assumed in modelling)** %								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
10	0,03	0,03	0,03	0,04	0,04	0,04	0,04	0,04	0,05
15	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,06	0,06
20	0,06	0,06	0,06	0,07	0,07	0,07	0,07	0,07	0,08
25	0,08	0,08	0,08	0,08	0,08	**0,09**	0,09	0,09	0,09
30	0,09	0,09	0,09	0,10	0,10	0,10	0,10	0,10	0,11
40	0,12	0,12	0,12	0,13	0,13	0,13	0,13	0,13	0,14
50	0,15	0,15	0,15	0,16	0,16	0,16	0,16	0,16	0,17
60	0,18	0,18	0,18	0,19	0,19	0,19	0,19	0,19	0,20

NOTE For solid wood products, the average result of 25-year and 35-year half-life is used (0,33+0,26)/2 = 0,3. For paper (fibre-based) products, 2-year half-life and 30 % recycling is used. A common scenario is that 25 % of the wood becomes solid wood products and 25 % becomes paper and paperboard – this scenario is marked in bold font.

The modelled results for roundwood in Table 4 appear to be supported by national inventory reports from EU member countries (Figure 9, Example 1A). This example from EU member countries shows how real values of the HWP coefficient for roundwood vary year to year between a low of 0,05 and a high of 0,21 with market shifts, indicating that a generic model value of 0,1 based on half-life calculation is a reasonable approximation.

7.4 Product residence time

7.4.1 IPCC country-specific half-lives

The IPCC recognises that there can be situations in which data quality and availability allows the modelling of the HWP pool to be refined. An example of this is given in 9.2, example 1, where national inventory report data is considered. The IPCC allows a tier 2 method for country-specific data based on this approach.[6] Averages for various subcategories of products, or 'commodity classes' are used to better represent the split of woody materials between different product types. The result is a country-specific half-life, which can be used for that country's HWP reporting. Similarly, where the HWPs are exported to other countries and a production approach is used, country-specific half-lives for the importing country's typical service lives and product categories are expected on this component. Note also that finished products are not covered by this tier 2 method – these are handled in tier 3 in the IPCC 2019 guidelines[6].

The IPCC tier 2 option uses known average lifespans for typical products to generate a country-specific half-life.[6] Reference service lives (RSL) can be derived from ISO 15686-1:2011 for various products or components as follows. The expected service life (ESL) can be deduced based on specific in-use conditions that might affect service life compared to the RSL value. Obsolescence factors are used to relate RSL and ESL, which can never be greater than 1. A factor of 1 is used when there is no need to adjust the ESL relative to the RSL value. Factors of values lower than 1 are used depending on the intensity of the obsolescence. Market share information is used with the obsolescence factor to account for early replacement (e.g. for aesthetic reasons rather than end of functional service). Then an adjusted extended service life is calculated to cover all components in the category, from which the country-specific half-life is derived, as the adjusted ESL × ln(2). In an example used, the following values for average service life of wood-based panels were used: 60 years for construction, 35 years for furniture, and 6 years for packaging. This appears to be a fictitious example and no country indication is made. The adjusted ESL is 30,5, and the resulting half-life calculated from this data is 21,2 years. In this example the refined half-life for the wood-based panel is shorter than the default half-life of 25 years.

The IPCC tier 3 first-order decay option allows finished products to be considered, in addition to semi-finished products. The reason for handling finished products separately from semi-finished products is to avoid double-counting of material.

7.4.2 Refining the IPCC country-specific half-life at an organizational level

The protocols outlined by the IPCC for determining a country-specific half-life can easily be followed to calculate a regionally specific half-life for the products supplied by an organization, which gives a tier 2 option for ISO 13391-1 HWP calculations.

Key considerations are the regions into which the products are sold, and the service lives (RSL and ESL) for these regions. Market dynamics can also be considered, for example if market growth is higher or lower than the 1,0 % default value.

In the example provided in 9.2 (Example 1), the national inventory report data can be used to generate a HWP coefficient value for use in organizational reporting.

7.4.3 Altering the function used to model residence time

Other methods for modelling residence time of wood-based products in the HWP pool besides first order decay can also be used under ISO 13391-1 tier 2.

The first step is to select a suitable mathematical function and apply it. Many researchers have identified that an S-shaped curve of quantity in service over time represents the lifespan of buildings or other wood-based products. Bohne et al.[13], using Norwegian data, modelled the ‘buildings still standing’ by age using a sigmoidal curve in which attrition rate was very low during the first 40 years of the building lives, followed by successively higher decay rates as the building age increased.

Usefully in this context, the S-shaped curve can be translated into a gaussian (or normal) distribution, or various related Weibull or Rayleigh distributions. Miatto et al.[21] summarise that the Dirac delta distribution, Weibull distribution and normal distribution are most commonly used in models of material flow for construction materials. They also considered gamma, Gompertz and log normal distributions. Thus, although a small number of buildings are demolished early, the majority serve long lifespans with an average service life of medium age, and a long tail of older buildings, before demolition of the final few buildings occurs at a considerable distance into the future. Ianchenko et al. (2020)[15] tested log-normal, gamma, and Weibull distributions against data for US residential housing stock and found that a Weibull distribution fit best, with an estimated average housing lifespan of 130 years. Distributions based on linear or gamma-functions, or modelled for life-spans based on uniform, linear, Weibull, normal or logistic distributions are reviewed by Brunet-Navarro et al.[14].

Similar distributions can be considered reasonable for many wood and wood-based product categories, whether in furniture or decking products, or as paper in newsprint. In the majority of cases probability is a significant component of residence time in the technosphere, which is a function of serviceability but also choices by the consumer not related to product function, such as replacement based on fashion.

NOTE If an HWP coefficient is not used, the contribution can be determined by calculating an inflow to and an outflow from the HWP pool.

7.4.4 Tier 3 calculation of HWP contribution

If the organization has primary data for both inflow and outflow, the HWP contribution can be calculated directly, according to Formula (2). However, many limitations exist with this method (see 9.4 for further discussion).

7.4.5 Considerations based on IPCC guidelines

The use of suitable mathematical functions is included in both the 2014 and the 2019 IPCC guidelines[6][7] for tier 3 methods to country-specific methods. In 2014 these were grouped into (a) flux data methods and (b) combinations of stock inventory and flux data methods.[7] The flux data methods use production data (i.e. the inflow into the HWP pool) with decay or discard rate data (to model the outflow from the HWP pool). It is noted that the discard rate data relies on reliable estimates of the lifespan of the HWP types rather than data from waste statistics, as reliance on this less accurate data would overestimate the quantities leaving the HWP pool (by including timber that had not been produced domestically). Many functions for decay rate are mentioned, including logarithmic functions, retention curves, and distribution functions (see Karjalainen et al.,[18] Skog and Nicholson[26] and Marland et al.,[19] respectively).

In IPCC[6] the flux data methods are mentioned, with the assumption that activity data can be established and combined with suitable service life information, differently than the commodity classes used in the tier 2 country specific method. For example, this can handle finished products, which are not suitable for consideration in tier 2 (to avoid double counting). Care is needed when considering the carbon included per piece when working with finished products such as window frames or wall systems. IPCC note that commodity classes ought to be broad enough to capture ‘significant carbon volumes contributing to the HWP pool’, this is indicated to be a volume of 5 % of total HWP.

The combined flux data and stock inventory methods options within tier 3 of IPCC[7] are where HWP stock inventory is used for one component of the analysis. In this method, data is available for two points in time, permitting a change of HWPs in the pool per year to be estimated. Examples include calculations based on change in building stock as a method for evaluating construction timber. Difficulties exist for national reporting based on this method, as the proportion of HWPs in the stock that arise from domestic timber production is not always known. However, interestingly the combined method can be used to consider situations where different building components have different service lives or replacement intervals.

In IPCC[6] the country specific direct inventory methods guidance were strengthened, suggesting that at least two, preferably more, separate points in time be used to estimate stock changes in the HWP pool. This was seen as only being suited to estimating stocks in the reporting country alone, for practical reasons. An example was annual change in carbon stock in finished wooden houses, as buildings are frequently a major part of the total HWP pool. It was suggested that estimations based on wood content per square metre of floor area can be used, with values for total floor area constructed. However, difficulties were identified if using this floor area method with the production approach, as the proportion of domestic versus imported timber in the structures cannot be handled, nor can the quantities of exported timber entering structures.

It was also acknowledged in IPCC[6] that there can be a need to combine direct inventory data with estimates derived from flux data methods. It was also commented that if a country used the direct inventory approach to handle HWPs in structures, it would be good practice to still estimate the other three default commodities (sawn wood, wood-based panels and paper and paper board) using a flux data method. However, in such cases the semi-finished products for structures would be factored out from the three commodities, to avoid double counting.

To gather country-specific service life data, or derive half-life values from it, the following comments from IPCC[6] are useful. Service lives can be evaluated based on the ISO 15686-1:2011 approach and can be used to consider national level service life and obsolescence to define RSL and ESL.

Depending on the organization's size, access to market intelligence and data related to product range and the destinations and mix of use types of their product mix might be relatively good, permitting flux data methods or stock inventory methods to be considered within tier 3. However, country or region-specific service life data would still be beneficial. Comments from IPCC[6] relating to the ISO 15686-1:2011 are useful. This establishes RSL values and ways to assess ESL values and obsolescence factors, see 7.4.1.

An alternative is to use a combination of production and trade statistics data with building inventory information. This option is most commonly done for HWP in buildings as building data is often readily available. For other wood and wood-based products, a similar approach can be taken when inventory data is available. A third option is to use data from national surveys on the final market use of wood. There has been a surge of interest in quantifying the wood-based products in the built environment and the service life data to predict exit from the HWP pool, for example studies in Austria[17] and Japan[20].

With this level of data, a tier 3 HWP coefficient can be calculated. For tier 2 and tier 3 approaches, information, statistics or models from the country's National Inventory Reporting systems can be used where available.

8 Data availability/Literature review

The lack of reliable data for product lifespan, discussed above, is one reason for the adoption of a half-life approach in the IPCC methodology for estimating the size of the harvested wood products pool in carbon accounting.[7] The half-life approach means that material is modelled as exiting the pool relatively rapidly in the early years after manufacture, slowing over time, and continuing to leave the pool at very low levels into a longer time horizon. This model is intended to take into account the wide range of lifespans within a category, namely that many short life products can exist, and longer life products can have lifespans which are increasingly dispersed across decades or centuries.

An early study by Pingoud et al.[24] used different average lifespans for various categories of paper and paperboard, leading to the observation of a 'plausible life age distribution'. Thus newsprint, household and sanitary grades were assumed to have a life of 0,5 years, linerboard, fluting and boxboard 1 year, then 80 % of printing and writing paper a life of 1 year, but 20 % of this grade a life of 10 years. This can be the origin of a model similar to a half-life, but an average lifespan of 0,8 years was defined by the authors for the paper and paperboard category as a whole.

A second study by Pingoud et al.[23] had moved towards a half-life system, using a simple first order decay model, and considering both half-life and average lifetime. The study used inventory data for Finland to investigate different average service lifetimes and concluded that for construction sawn wood 39 years gave a good match, while for buildings and garden construction 31 years average lifetime was a good match. Thus, they proposed that average service life for sawn wood in Finland was less than 40 years but did not provide a half-life.

Karjalainen et al.[18] considered that forest products could be represented by different lifespan categories in a 200-year simulation. They used lifespans defined by half-lives, with 65 years for long lifespan, 30 years for medium lifespan, 13 years for medium-short lifespan and 4 years for short lifespan products. At end of life, one third of the material leaving service was recycled, one third landfilled and one third used for energy generation. Recycling had a benefit on the total quantity of carbon stored. The effect of extending the product lifespan by 10 % was also considered.

Marland et al.[19] give a good overview of progression ideas within the IPCC documents, including the definition of three and later four 'approaches' and different tiers of methods. This includes the origins of the move from simple decay to first order decay and other decay functions over the time. They report that a VTT report by Pingoud and co-workers in 2003 had compiled a lengthy list of published half-life values.

Sikkema et al.[25] used the half-life methodology to demonstrate the combined benefits of substitution of higher carbon materials by wood and carbon uptake/storage in wood-based products for Canadian case studies. This included the cascading use of solid wood into wood-based panels and fuel applications. However, they highlighted the need for further research to better address greenhouse gas allocation across countries.

Spear[28] used a normal distribution curve to handle wood-based panels entering selected applications in the technosphere. These ranged from short life to long life scenarios, including shop fitting, temporary building site timbers, packaging, furniture, joinery and construction timber. When plotted across a range of markets, the difference between the profile of residence times compared to the half-life profile was pronounced, and there was a tendency to overestimate the quantity of material in mid-range service lives (20-60 years) when using half-lives, and a tendency to underestimate the long-range pool (60+ years). When the same average service life data were used within the IPCC's tier 3 method to calculate a region-specific half-life, the result was 19,2 years. This made only minor change to the shape of the half-life curve, and the problem with underestimation of mid-range and overestimation of long range persisted.

Miatto et al.[21] highlight that when considering the likelihood of demolition from a practical point of view, experience suggests that apart from catastrophic events or exceptional structural inefficiencies, very few structures and buildings are likely to get demolished in the immediate period after construction. The peak demolition likelihood occurs after some time has passed, based on location, period, typology of construction, maintenance, social factors etc (Thomsen and van der Flier[29]). Similar effects were suggested by Spear et al.[27] Based upon these observations Miatto et al.[21] highlighted that the log-normal distribution was a promising candidate for considering building demolition rates. Other right-skewed distributions also showed promising results in studies on data from Japanese building stock. However, when looking at data from Salford UK, they showed that the Gompertz distribution was closest, followed by the normal, logistic and Weibull distributions, but this related to the specific history of that city development and re-development.

NOTE The differences in terminology in this clause is due to and in line with the terminology used in the referenced articles.

9 Examples of methods for calculating HWP coefficients

9.1 Assumptions

The examples below illustrate how the HWP coefficient can be calculated for specific product categories.

The inflow to the HWP pool is established by the product quantity delivered in the specified time period.

For the outflow from the HWP pool in the specified time period, two basic assumptions are made for the calculations:

a) The half-life of the product category, expressing the time in years after which half the product category quantity remains in use. The default half-lives under ISO 13391-1:2025, 5.4.2, tier 1 are based on IPCC

Guidelines[6] and are 35 years for sawn wood, 25 years for wood-based panels and 2 years for paper and paperboard.

b) The proportion of recycling, expressing the amount of wood-based material that is recycled for use in similar products. This can be simplified by treating sawn wood and wood-based panels as a single HWP category.

9.2 Example 1: Using national inventory reports and country-level statistics on wood-based products

Changes in the HWP pool are included in national inventory reports that countries submit to the United Nations Framework Convention on Climate Change (UNFCCC). This applies to the “Annex 1 countries” to the convention (UNFCCC[3]). National inventory reports (NIRs) are submitted annually and published on the UNFCCC website (UNFCCC[4]), making the data publicly available. Methods for reporting of the HWP pool and its changes are specified by IPCC[6], with country-level considerations recorded in respective national inventory reports.

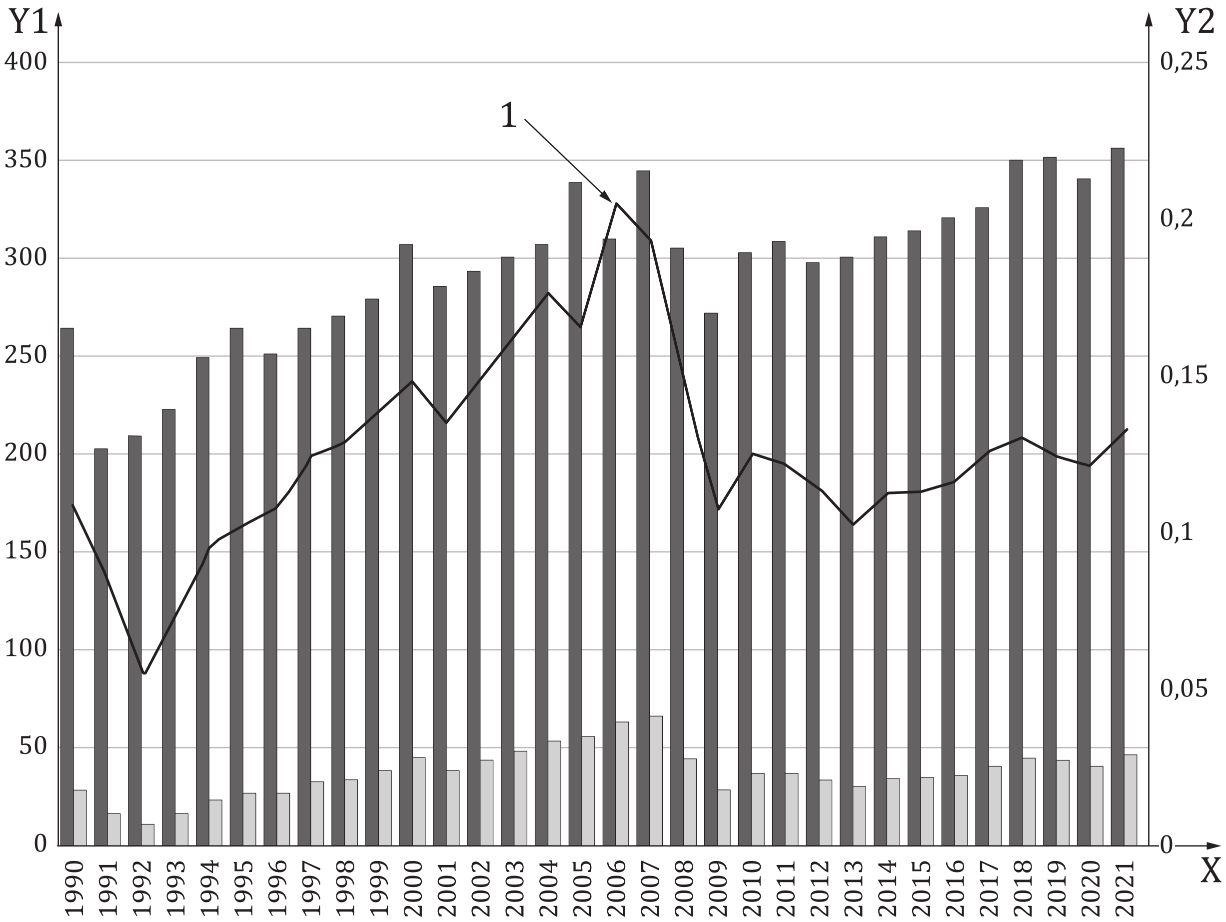
The HWP pool change usually refers to products based on wood harvested in the producing country, excluding products based on imported wood (e.g. Statistics Sweden[12]), although the IPCC Guidelines also allow for inclusion of imported wood within different approaches (these approaches are described in 5.2.1).

The NIRs have applied assumptions and the IPCC Guidelines to establish the HWP pool balance through current inflows and outflows of material based on historical production data at the national level. This offers an opportunity to calculate proxy HWP coefficients at country level, or for a combination of countries, which can then be applied as empirical approximations at the organizational level.

One limitation of this approach is that calculations can be straightforwardly made at the roundwood level, but detailed data for different product categories are often absent. One exception is Sweden, where the HWP pool changes for product categories are part of the official national statistics[12].

Individual countries or regions can have experienced high variability in wood-based product outputs, including countries with short historical harvest timeseries, high market growth, or declining industry output. Under such circumstances, adopting nationally reported HWP pool changes for calculations at organizational level could result in distorted or unrealistic reporting. Applying a model based on world market developments provides a more stable basis for the calculation within organizational reporting.

Case A: The European Union compiles NIRs for all its Member States and makes the statistics publicly available (European Environment Agency[9]). Combined with production data of industrial roundwood from FAOSTAT[5], the HWP coefficient for roundwood can be calculated as (HWP pool change/inflow of industrial roundwood). Figure 9 illustrates this for the EU as a whole.



Key

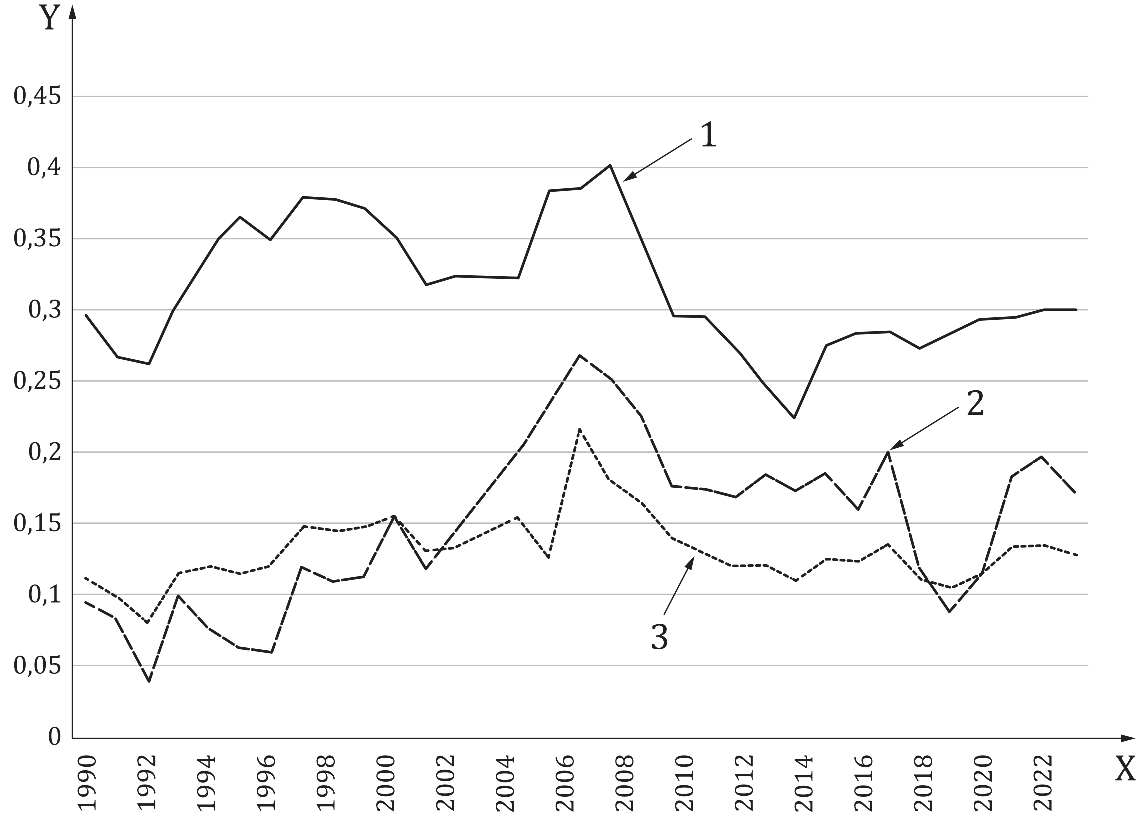
X	calendar years
Y1	Mt CO_2e/year
Y2	HWP coefficient
1	calculated HWP coefficient for industrial roundwood (using Y2)
(dark grey bar)	industrial roundwood production (using Y1)
(light grey bar)	reported HWP pool change (using Y1)

NOTE Based on the industrial roundwood production (2) and reported HWP pool change (3),[5][9] the HWP coefficient for industrial roundwood per year (1) is calculated.

Figure 9 — Industrial roundwood production and reported net change in the HWP pool for 1990 to 2021 in the European Union

As seen in the Figure 9, HWP coefficient values fluctuate year on year, because they are closely related to market inflow data. As a result, it would be necessary to consider a long time period to gain a representative average HWP coefficient value.

Case B: Sweden provides official statistics for the total change of the HWP pool, as well as disaggregated data by the main product categories of sawn wood, wood-based panels, and paper and paperboard.[12] Combined with annual production statistics from FAOSTAT[5] for roundwood and the product categories, HWP coefficients for each product category can be approximated as (HWP pool change/inflow of products), see Figure 10. Due to recent fluctuations in the volumes of wood-based panels produced in Sweden, the categories sawn wood and wood-based panels have been combined into “solid wood products”.



Key

X calendar years

Y HWP coefficient

1 solid wood products (combination of sawn wood and wood-based panels)

2 paper and paperboard

3 industrial roundwood

NOTE The data comes from References [5] and [12].

Figure 10 — Calculated approximate HWP coefficient for roundwood and main product categories based on official statistics for Sweden

9.3 Example 2: Using market development data

As established above, the HWP pool net change in a specified time period can be determined as the difference between current inflow of products and current outflow of historically delivered product quantities. ISO 13391-1 defines a HWP coefficient (k_{HWP}) as the proportion of current inflow that represents the net change for a product category as shown in 7.2, Formula 4.

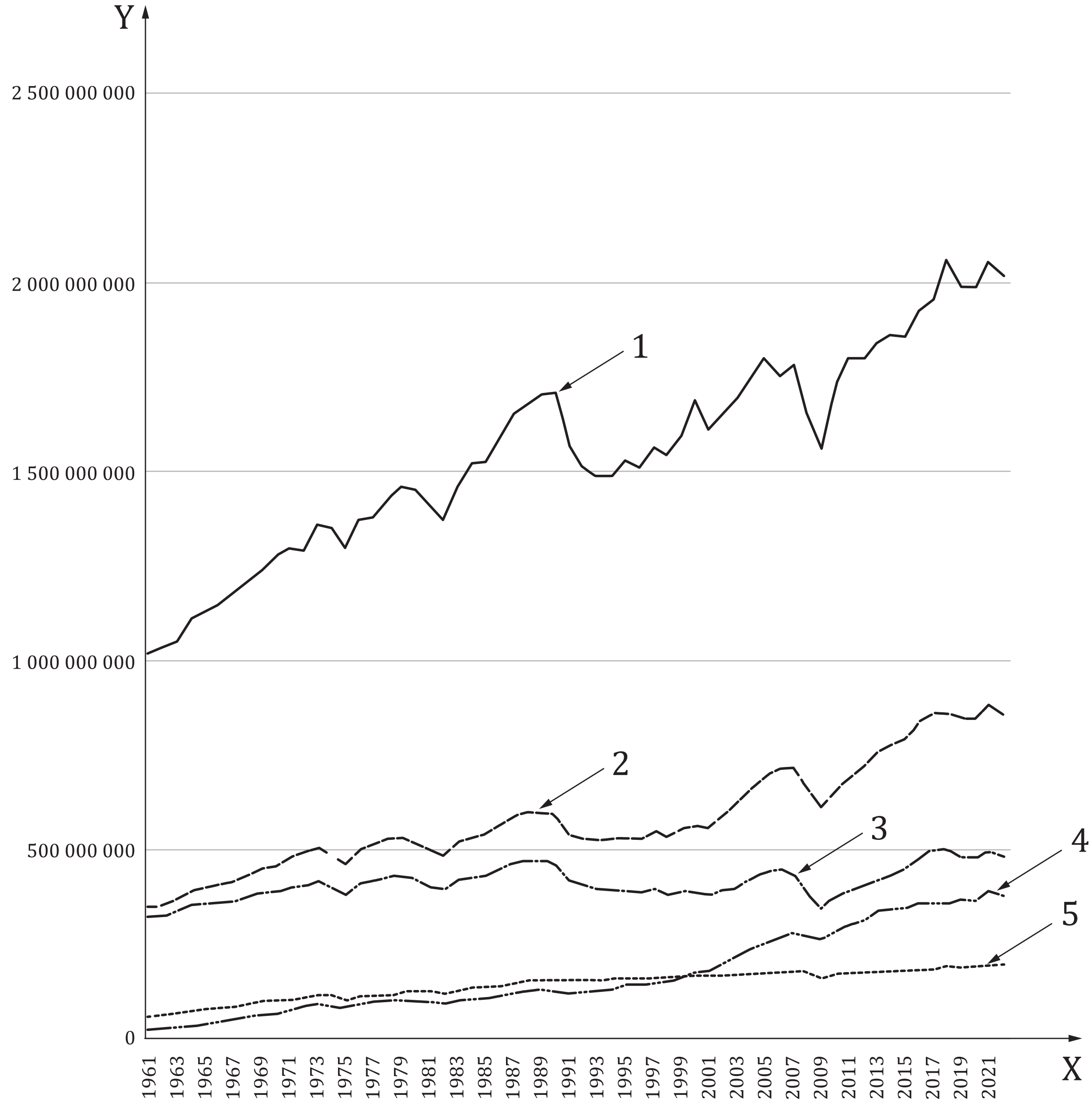
The outflow depends on assumptions on the longevity of products, including recycling phases, as well as data on historically delivered product quantities – the market development over time. Expanding market volumes will lead to situations where the inflow of carbon is larger than the outflow, i.e. positive HWP coefficients. Correspondingly, decreasing market volumes will lead to negative HWP coefficients.

It is important to note that there is considerable inertia in the level of outflow, as changes in the short term of product outputs will be manifested over a long time period.

In 7.2, Table 3 used a market growth rate within the model to define HWP coefficient values. Knowing the market growth rate is important as it influences the development of the HWP coefficient.

Data on market developments can be useful as a base for calculating outflows from the HWP pool and further in determining HWP coefficients that can be used as proxies at the organizational level. In this example, global market data are used, under the assumption that most industrial wood-based products are delivered and traded on a world-wide market.

The FAO statistical services[5] provide annual data for a range of wood-based product categories from 1961 onwards, on country, regional and global levels. Figure 11 illustrates the development of global market volumes 1961 to 2022. Table 5 shows the compound increase rates for product categories in different time periods. Using the data from Figure 11 and the values in Table 5, it appears that the market growth rate of 1 % which was used in 5.4 and 6.2 is reasonable for industrial roundwood.



Key

X calendar years

Y production volume (different units are used and are shown in brackets after 1-5)

1 industrial roundwood (m^3)

2 combination of sawn wood and wood-based panels (m^3)

3 sawn wood (m^3)

4 wood-based panels (m^3)

5 wood pulp (t)

NOTE The data comes from Reference [5].

Figure 11 — Market volume developments 1962 to 2022 for main product categories

Table 5 — Increase and compound/linear increase rates for main product categories for different time periods based on official statistics[5]

	Industrial roundwood	Sawnwood	Wood-based panels	Sawnwood + wood-based panels	Wood pulp	All products CO_2e
	1961 to 2022					
Total increase, multiple	1,98	1,49	14,93	2,46	3,18	2,62
Compound rate of change	1,1 %	0,7 %	4,5 %	1,5 %	1,9 %	1,6 %
Linear rate of change	1,6 %	0,8 %	23,2 %	2,4 %	3,6 %	1,6 %
	1992 to 2022					
Total increase, multiple	1,34	1,19	3,03	1,62	1,28	1,52
Compound rate of change	1,0 %	0,6 %	3,8 %	1,6 %	0,8 %	1,4 %
Linear rate of change	1,1 %	0,6 %	6,8 %	2,1 %	0,9 %	1,1 %
	2012 to 2022					
Total increase, multiple	1,12	1,19	1,20	1,19	1,14	1,18
Compound rate of change	1,2 %	1,8 %	1,8 %	1,8 %	1,3 %	1,7 %
Linear rate of change	1,2 %	1,9 %	2,0 %	1,9 %	1,4 %	1,2 %

NOTE "Linear rate of change" is short for "linear rate of change as a percentage of the production volume at the start of the period".

The rates of increase of the world market can be used to establish HWP coefficients for product categories through modelling as elaborated further in Clause 7. Based on historical real-world development of global markets, a general and conservative compound market growth rate of 1 % can be assumed for the HWP coefficient calculations.

9.4 Using organization-specific data

This document does not provide any comprehensive examples of using organization-specific data as no viable example has been found.

However, an organization can apply its own data for calculating the HWP outflow, either based on half-life assumptions, or based on other assumptions on the longevity of its products. This would build on time series of historical quantities of delivered products from the organization, so as to establish the current rate of outflow from the HWP pool of its historically delivered products.

However, the time series would have to be up to a century long to achieve relevant results, given that the half-life of some wood-based products are counted in decades. For relevant results, the historically delivered quantities would have to represent the organization as it is defined today. Most organizations have experienced constitutional changes over such a long time period, for example due to mergers and acquisitions, which means that establishing a consistent time series of delivered product quantities can be challenging.

9.5 Note on sensitivity related to assumptions and limitations in the examples

9.2, 9.3 and 9.4 above implies assumptions or limitations that can impact the resulting HWP coefficient.

9.2: Using empirically reported HWP pool changes and corresponding production quantity is often limited to aggregated data for roundwood production or broad commodity classes, as published statistics for different product categories are not generally available. Disaggregating such data to specific product categories is sensitive to further assumptions and can introduce additional uncertainties.

9.3: Long-term market developments can be a robust proxy for modelling the development of the HWP pool (see Clause 6). The results will, however, be sensitive to the market growth rate that is applied and whether, e.g., a compound or linear market growth is applied based on historical data. Further, global market developments do not always reflect the HWP pool contributions at regional or local levels. The modelling will also be sensitive to assumptions of half-lives and recycling rates.

9.4: Consistent long-term production data at the organization level is needed to establish organization-specific HWP coefficients, given the long half-lives of many wood-based products. Even in the rare case where the long-term history of an organization is known, comparing historical production data can be challenging and introduce uncertainties. Moreover, individual organizations can have experienced variations of production levels over time, which are not an accurate basis for calculating HWP contributions today.

10 HWPs in landfill and other methods of woody carbon storage

10.1 General

Clause 10 considers HWPs in landfill and other methods of woody carbon storage beyond the general use of HWPs. Such methods can include HWPs used in bio-CCS, and other bio-based carbon capture methods such as biochar and burial.

The focus of this clause is HWPs in solid waste disposal sites (SWDS) or landfills, as data is widely available, and this form of storage is described in ISO 13391-1:2025, 5.5.2. However, the principles developed here can be easily deployed to consider bio-CCS, biochar and burial when these technologies become widely adopted and regional or national data becomes available.

10.2 Tier 1 approach for landfill carbon storage

Working at the organizational level, a simple estimate of the quantity of wood-based products entering landfill can be obtained using the quantity of wood-based products sold into the market by that organization, with a regionally relevant factor to represent the fraction of wood currently moving into landfill.

This approach uses current wood recovery and landfill statistics to generate the factor, as the future factor cannot be known with any degree of certainty.

In ISO 13391-1, this results in the following Formula (5):

$$m_{i,\mathrm{ent}} = w_{i,\mathrm{rec,l}} \times m_i \tag{5}$$

where

$m_{i,\mathrm{ent}}$ is the quantity of woody material of product *i* entering landfill in the specified time period, expressed in t, wet basis;

$w_{i,\mathrm{rec,l}}$ is the fraction recovered for landfill in the specified time period;

m_i is the quantity of woody material of product *i* placed on the market in the specified time period, expressed in t, wet basis.

NOTE Other approaches for modelling or estimating the quantity of wood entering landfill are possible, and will be explored in tier 2 options, in 10.4.

Once the quantity of wood-based products entering landfill is known then two further considerations are made.

— Within the landfill the decay rate of woody material would be considered. This is handled by the IPCC's DOC value, degradable organic carbon. A value of 0,4 is typically used for wood, and a value of 0,3 is used for paper, paperboard and textiles.

— A fraction is used to evaluate the organic carbon dissimilated (converted to landfill gas), this is the $\mathrm{DOC_f}$ value ($w_{\mathrm{DOC,diss}}$ in the formula below in accordance with ISO's writing rules), as used in the IPCC's methodology. Typical $\mathrm{DOC_f}$ values are 0,1 for wood and 0,5 for paper, paperboard and textiles.

In ISO 13391-1, this results in the following Formula (6):

$$w_{i,\mathrm{rem}} = m_{i,\mathrm{ent}} \times w_{\mathrm{DOC}} \times \left(1 - w_{\mathrm{DOC,diss}}\right) \times \frac{44}{12} \quad (6)$$

where

$w_{i,\mathrm{rem}}$	is the biogenic carbon in woody material remaining in landfill, expressed in t CO_2e;
w_{DOC}	is the fraction of degradable organic carbon per mass of wood;
$w_{\mathrm{DOC,diss}}$	is the fraction of w_{DOC} that is dissimilated (converted to landfill gas).

While it is logical to expect that the type of landfill is known, as this will govern the decay rate, in practice many engineered landfills have very similar decay rates. It is possible to consider this aspect further within tier 2 or 3 methods but it is not required within tier 1. Such considerations require additional information such as regional knowledge of typical practices in the area.

10.3 Considering non-standard landfills

Where landfilling occurs in unregulated sites, for example without appropriate sealing or design, the proportion of biogenic carbon which is dissimilated is likely to increase. This increase in aerobic and anaerobic processes can be handled by choice of suitable degradable organic carbon (DOC) factor and organic carbon dissimilated ($w_{\mathrm{DOC,diss}}$) factor.

In unmanaged landfills there is also the possibility of material from the landfill being reclaimed and removed by scavenging. Wood is a valuable commodity in this context – either for informal reuse and recycling, or for energy purposes. This circumstance renders it difficult to claim long-term storage wood in SWDS, as the destination in energy or other applications cannot be easily quantified. Thus, some local knowledge for the country or region is helpful.

10.4 Tier 2 methods for material entering landfill using half-life

10.4.1 General

When using the tier 1 or tier 2 approach based on first order decay to evaluate HWP components and HWP coefficient values (as set out in Clauses 5 and 7) it is possible to extend this model to consider the material exiting the HWP pool, and its split into recycling, energy, landfill and other categories (e.g. degradable carbon emitted to atmosphere).

The half-life model generates an outflow of HWPs at each year, and as the model stabilises (and i.e. when the HWP coefficient approaches the asymptote) similar coefficients can be derived for the destinations of these HWPs exiting from the in-use pool, with appropriate factors for regional split of energy, recycling and landfill activity. The initial input to the calculation of different HWP destination coefficients is the gross outflows, including recycling, obtained from the HWP model (see Clause 7).

Then, for each country or region, the appropriate split of timber within these outflows into recycling, energy and landfill can be used for each country or region.

Precautionary note: Using the tier 1 HWP carbon model (as described in Clauses 4 to 6) to derive the quantity of outflow from the in-use HWP pool per year can be prone to substantial errors. This is due to the tendency for HWP coefficient values to underestimate the quantity stored in the in-use HWP pool, leading to a tendency to overestimate the quantity not retained, i.e. entering recycling or bioenergy or landfill. In calculating an HWP coefficient value (as set out in Clauses 4 and 6), the aim is to generate a conservative value that will not overestimate storage effects but will reflect fluxes in a very stable market. The outflow coefficient and the quantity of outflow estimated based on one minus the HWP coefficient (i.e. 1-k_{HWP}) is therefore prone to being less conservative, as it includes anything that cannot be sure to be stored. It contains considerably more error than the HWP coefficient value and is likely to overestimate the quantity leaving the HWP in use pool in that time period.

The following equations use US specific data and assumptions as an example of how to estimate carbon contribution of HWPs after they exit the in-use pool (not necessarily the same as IPCC values). These data and assumptions might not apply to locations outside of the US.

All coefficients and parameters used in the example calculation in the next subclause are summarized in Table 6.

Table 6 — Summary of HWP model parameters and data and assumptions used to calculate carbon stored in SWDS and emitted via burning and decay in SWDS after wood leaves the HWP pool

Parameters, data and assumption	Value	Source
Half-life sawnwood	35 years	HWP model
Annual recycling rate	17,1 %	US recycle rate; applied in HWP model
Market growth (compound annual growth rate)	1 %	HWP model
Estimated coefficients at year 200		
HWP coefficient	0,38	HWP model
Outflow coefficient (1- HWP coefficient)	0,62	HWP model
Annual burning rate of products leaving the HWP pool	15,7 %	Reference [10]
Annual SWDS rate of products leaving the HWP pool	67,2 %	Reference [10]
Proportion of nondegradable HWPs in SWDS	77 %	Reference [11]
Proportion of degradable HWPs in SWDS	23 %	Reference [11]
Half-life of degradable HWPs in SWDS	29 years	Reference [11]
Degradable SWDS coefficient	0,046	Calculated by applying first order decay of SWDS degradable pool with a half-life of 29 years (see the spreadsheet named “Spread-sheet End of life”, which is available at https://standards.iso.org/iso/tr/25080/ed-1/en)

10.4.2 Recycling

Because the HWP coefficients and the outflow quantities are calculated with recycling included, a separate calculation for recycled HWPs is not provided. The HWP coefficient used in the example calculations below was obtained from using the HWP model (described in Clauses 4 to 6) with a US specific recycle rate of 17,1 %[10].

10.4.3 Burning for energy

Some portion of HWPs can be burned to generate energy. The amount of carbon emitted via burning of products leaving the HWP pool can be calculated by multiplying the outflow (quantity of HWPs exiting from the in-use pool) with the country specific percentage of outflow that is burned for energy as follows:

$$m_{\mathrm{C,burnt}} = m_{\mathrm{out}} \times w_{\mathrm{C,burnt}}$$

where:

$$m_{\mathrm{out}} = m_{\mathrm{HWP,in}} \times k_{\mathrm{out}}$$

$$k_{\mathrm{out}} = 1 - k_{\mathrm{HWP}}$$

Examples of tier 1 HWP coefficients are provided in Tables 1 and 2 in Clause 6. For the purpose of the example calculations provided below, the calculated HWP coefficient at 200 year is 0,38, which results from using HWP model with a recycle rate of 17,1 % (see Clauses 6 to 7 and the attached spreadsheet of end-of-life calculations).

In the United States, the current proportions of discarded wood that is burned for energy are estimated at 15,7 % for wood-based products and 6,2 % for paper and paperboard, respectively.[10] We can use these percentages and HWP coefficient to estimate the carbon emitted via burning after they leave the HWP pool. For example, if an organization in the US added 500 t CO_2e of sawnwood in the market at a given year, then using these percentages and HWP coefficient of 0,38 (obtained using HWP model applying a US specific 17,1 % recycle rate, see the attached spreadsheet of end-of-life calculations), carbon emission attributed to the organization via burning at any given year would be:

$$m_{\mathrm{C,burnt}} = 500\ \mathrm{t\ CO_2e} \times (1-0{,}38) \times 0{,}157 = 48{,}670\ \mathrm{t\ CO_2e}$$

10.4.4 Landfilling

10.4.4.1 General

The quantity of outflows remaining after recycling and burning end up going to SWDS or landfills. Using a US example, the current rate of landfilling is estimated at 67,2 % of wood-based products and 25,6 % of paper and paperboard.[10] A portion of the SWDS HWPs is nondegradable and carbon contained in this portion of the HWPs are considered to be stored indefinitely. The other portion of the SWDS HWPs is degradable. Carbon contained in this portion of the HWPs decays slowly over time and is estimated in a similar manner to the HWP model, based on assumed half-lives and first order decay function. The sum of coefficients for these two components provides the coefficients for carbon remaining in HWPs in landfill. The example calculation of the carbon stored in SWDS is shown in 10.4.4.2 using the US specific data and assumptions.

10.4.4.2 HWP carbon stored and emitted in SWDS

The carbon stored in SWDS depends on the country specific fraction of SWDS HWPs that is nondegradable. For instance, in its annual greenhouse gas inventory report to UNFCCC, the US assumes 77 % of SWDS wood-based products are non-degradable.[11] Using these percentages, carbon stored in the nondegradable portion of SWDS wood-based products pool will be:

$$m_{\mathrm{SWDS,C,\,nondeg}} = m_{\mathrm{SWDS,in}} \times w_{\mathrm{SWDS}} \times w_{\mathrm{C,nondeg}}$$

where:

$$m_{\mathrm{SWDS,in}} = m_{\mathrm{HWP,in}} \times k_{\mathrm{out}}$$

$$k_{\mathrm{out}} = 1 - k_{\mathrm{HWP}}$$

w_{SWDS} is the annual SWDS rate of products leaving the HWP pool

As an illustration, if an entity in the US added 500 t CO_2e of sawnwood in the market at a given year, then using the US specific data and assumptions and HWP coefficients obtained from HWP model applying a 17,1 % recycle rate (see the spreadsheet named “Spreadsheet End of life”, which is available at https://

standards.iso.org/iso/tr/25080/ed-1/en), its carbon contribution to the nondegradable SWDS pool in any given year will be:

$$m_{\mathrm{SWDS,C,\,nondeg}} = 500\ \mathrm{t\ CO_2e} \times (1-0{,}38) \times 0{,}67 \times 0{,}77 = 160{,}406\ \mathrm{t\ CO_2e}$$

Carbon contribution of degradable portion of SWDS can be calculated by estimating the degradable SWDS carbon coefficient when it approaches the asymptote using the first order decay function and assumption of half-life, similar to the approach used in estimating HWP coefficients described in Clause 6:

$$k_{\mathrm{SWDS,deg}} = \frac{m_{\mathrm{SWDS,in}} - m_{\mathrm{SWDS,out}}}{m_{\mathrm{SWDS,in}}}$$

Using the outflows from the HWP model described in Clauses 6 and 7, and using the US specific assumption that 67 % of outflows enters SWDS and that 23 % of these SWDS inflows are degradable, and that these products have 29 years of half-life, the estimated degradable SWDS coefficient at 200 year is 0,046 (see the spreadsheet named “Spreadsheet End of life”, which is available at https://standards.iso.org/iso/tr/25080/ed-1/en). Using this coefficient, we can calculate the carbon stored in degradable portion of the SWDS. As an illustration, if an organization in the US added 500 t CO_2e of sawnwood at a given year, then the degradable SWDS carbon contribution of that organization at 200 years will be:

$$m_{\mathrm{SWDS,C,\,deg}} = m_{\mathrm{SWDS,\,in}} \times k_{\mathrm{SWDS,\,deg}}$$

where:

$$m_{\mathrm{SWDS,\,in}} = m_{\mathrm{HWP,\,in}} \times k_{\mathrm{out}}$$

$$k_{\mathrm{out}} = 1 - k_{\mathrm{HWP}}$$

Thus,

$$m_{\mathrm{SWDS,C,\,deg}} = 500\ \mathrm{t\ CO_2e} \times (1-0{,}382) \times 0{,}046 = 14{,}388\ \mathrm{t\ CO_2e}$$

Thus, the total SWDS carbon contribution of the organization will be the sum of nondegradable and degradable carbon contributions. That is,

$$m_{\mathrm{SWDS,C}} = m_{\mathrm{SWDS,C,\,nondeg}} + m_{\mathrm{SWDS,C,\,deg}} = 160{,}406\ \mathrm{t\ CO_2e} + 14{,}388\ \mathrm{t\ CO_2e} = 174{,}794\ \mathrm{t\ CO_2e}$$

Thus, out of 500 t CO_2e of sawnwood added by an organization in the US in a given year, the calculations show the following contributions to biogenic carbon and storage and emissions at 200 years.

HWP carbon contribution = 190 t CO_2e

SWDS carbon contribution = 174,794 t CO_2e

Total HWP carbon contribution = 190 t CO_2e + 174,794 t CO_2e = 364,794 t CO_2e

Carbon emitted via burning and SWDS decay = 500 t CO_2e – 364,794 t CO_2e = 135,206 t CO_2e

10.4.4.3 Other considerations

The users can replace the parameters in both the HWP and end-of-life spreadsheet models based on the actual data in specific country or region and get the updated results. These spreadsheets are named “Spreadsheet HWP coefficient model” and “Spreadsheet End of life” and are available at https://standards.iso.org/iso/tr/25080/ed-1/en.

Methane is emitted from landfills, but neither this document nor the HWP contribution described in ISO 13391-1 consider these emissions. Methane emissions would be considered within the value chain emissions calculations of ISO 13391-1:2025, 5.5.2.1 in order to be consistent and matched with the landfill assumptions for the HWP storage component. Methane emissions can be estimated based on the degradable outflow (column k in “Spreadsheet End of life”, which is available at https://standards.iso.org/iso/tr/25080/ed-1/en).

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