METHODOLOGY DESCRIPTION FOR THE FOREST CARBON SEQUESTRATION TOOL (THE FRESCOS TOOL)

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GLOSSARY

The terminology of this document is in line with the definitions according to the Intergovernmental Panel on Climate Change (IPCC, 2003[1], 2006[2] and IPCC, 2014[3]).

Term	Abbr.	Description	Reference
Aboveground biomass	AGB	All living biomass above the soil (incl. stems, stumps, branches, bark, seeds and foliage)	IPCC, 2006: Volume 4, Chapter 4, Glossary
Agriculture, Forestry and Other Land Use Sector	AFOLU	Agriculture, Forestry and Other Land Use. Segment of the economy where the mitigation potential is derived from both improvement of GHG removals and reduction of GHG emissions through management of land and livestock	IPCC, 2014: WG III AR5, Chapter 11, Executive Summary
Basic wood density	D	Ratio between oven dry mass and fresh stem-wood volume without bark (t/m^3)	IPCC, 2006: Volume 4, Chapter 4, Glossary
Belowground biomass	BGB	All biomass in live roots (excluding fine roots)	IPCC, 2006: Volume 4, Chapter 4, Glossary
Biological carbon stock		A carbon pool that is of biological origin (for example vegetation)	
Biomass expansion factor	BEF	Dimensionless multiplication factor that expands the merchantable volume to the total AGB volume to account for non-merchantable parts of the tree	IIPCC, 2006: Volume 4, Chapter 4, Glossary
Carbon flux		Transfer of carbon from one pool to another in units of measurement of mass per unit of area and time (e.g., tC/ha/a)	IPCC, 2003: Glossary
Carbon stock		The quantity of carbon in a pool	IPCC, 2006: Volume 4, Chapter 4, Glossary
Carbon stock change		The change in a carbon stock due to carbon gains and losses. Can be expressed in units of carbon or carbon dioxide.	IPCC, 2006: Volume 4, Chapter 4, Glossary
Cropland	C	Cropped land, including rice fields, and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category	IPCC, 2006: Volume 4, Chapter 3, Section 3.2
Dead wood	DW	All non-living biomass that is not contained in the litter. Can be standing, lying on the surface or in soils	IPCC, 2006: Volume 4, Chapter 4, Glossary
Dead organic matter	DOM	Biological carbon pool that consists of dead wood and litter	IPCC, 2006: Volume 4, Chapter 1, Glossary
Emission		The release of GHG into the atmosphere	IPCC, 2006: Glossary

[1] IPCC, 2003. Good Practice Guidance for LULUCF
[2] IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
[3] IPCC, 2014. Climate Change 2014 Mitigation of Climate Change - Working Group III Contribution to the Fifth Assessment Report (WG III AR5) of the Intergovernmental Panel on Climate Change

Forest Land	FL	All land with woody vegetation	IPCC, 2006: Volume 4, Chapter 4, Glossary
Growing stock		Volume over bark of all living trees more than X cm in diameter at breast height. Includes the stem up to a top diameter of Y cm. Countries indicate the X and the Y values.	IPCC, 2006: Volume 4, Chapter 4, Glossary
Harvested wood products	HWP	All wood material that leaves the harvest site	IPCC, 2006: Volume 4, Chapter 12, Section 12.1
The Intergovernmental Panel on Climate Change	IPCC	The United Nations body for assessing the science related to climate change	IPCC, 2014: WG III AR5, Foreword
Land use and land-use change	LULUCF	Greenhouse gas inventory sector that is a subset of the AFOLU sector. It covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities excluding agricultural emissions and removals	IPCC, 2014: WG III AR5, Glossary
Land-use category		Categories, defined for inventory purposes in the IPCC Guidelines (2006), that enable the inclusion of all managed land area within a country	IPCC, 2006: Volume 4, Chapter 3, Section 3.2
Land-use conversion		Change of land-use category to another	IPCC, 2006: Volume 4, Chapter 4, Glossary
Litter	LI	Non-living biomass in various states of decomposition either above or within soil (incl. fine roots, and small diameter dead roots)	IIPCC, 2006: Volume 4, Chapter 4, Glossary
Living biomass		Living organic material both aboveground and belowground	IPCC, 2003: Glossary
Mean annual increment	MAI	The average annual increase in the merchantable part of the living tree (m^3/ha)	
Merchantable volume		The volume over bark of all trees defined using the conditions described for growing stock - applies on both living and harvested trees	IPCC, 2006: Volume 4, Chapter 4, Glossary
Removal		Removal of GHG from the atmosphere by a sink	IPCC, 2006: Glossary
Sequestration		The process of storing carbon in a carbon pool	IPCC, 2006: Glossary
Soil organic matter	SOM	Includes carbon in live and dead fine roots and other DOM within the soil that cannot be distinguished empirically	IPCC, 2006: Volume 4, Chapter 4, Glossary
Stratum		A subcategory of land area that has unique biophysical and management conditions such as vegetation type, age class, soil type and management type	

FOREWORD

FRESCOS background by the involved EDFI team

The overall goal of the FRESCOS Tool is to better account and analyse the carbon balance of the forestry and agroforestry projects. This information is then further used to estimate the annual net emissions of our investment portfolio. As development financiers, climate change mitigation and adaptation are at the very core of our work, and we strive to better understand and manage our investments also in terms of carbon sequestration.

For emission accounting, adequate tools and a methodology are already publicly available, but for carbon sequestration the publicly available tools or the methodology have not been as adequate. Many tools for accounting the carbon sequestration of afforestation and reforestation projects have not been accurate enough and lack the possibility to follow annual changes. During the years we have tested many tools, but the wanted to develop a tool to allow better usability and accuracy. The general data used by many existing tools seemed to overestimate the carbon sequestration of our projects and lack the details of annual changes and different carbon fluxes, such as harvested wood products.

For these reasons, we teamed up to create a new tool to account the carbon sequestration. With the FRESCOS Tool, our purpose is to account the annual carbon sequestration with as much of primary data collected from the investee companies to produce the most accurate results as possible. The FRESCOS Tool can be used for project accounting on an annual or scenario basis. The tool can be used by forestry companies or forestry investors who are interested to understand, monitor and disclose the climate impact of a forestry project, includingtheir financed carbon sequestration and carbon emissions. The PCAF methodology, the global GHG accounting and reporting standards for the financial industry, should be used by investors to attribute the results the FRESCOS Tool provides.

As European Development Finance Institutions (EDFI), we hope that the FRESCOS Tool will become a useful tool not only for ourselves but for every organisation interested in gaining data on carbon sequestration and better understanding the impact the forestry projects can have.

That is why we also wanted to make the methodology and tool free and publicly available. We hope you find it useful.

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DISCLAIMER

The objective of the document 'Methodology description for the Forest Carbon Sequestration Tool' (the FRESCOS Tool) is to describe the methodology for estimating carbon emissions and removals of forestry and agroforestry projects used in the FRESCOS Tool. All information is merely for educational and informational purposes. It is not intended as a substitute for professional advice. While the information has been verified to the best of our abilities, we guarantee neither the accuracy/completeness of any information contained in this report, nor that it is free from mistakes and error. Should you decide to act upon any information based on the described methodology and/or FRESCOS Tool, you do so at your own risk

1. INTRODUCTION

The objective of this document is to describe the methodology for estimating carbon sequestration and emissions from forestry and agroforestry projects used in the FoRESt Carbon Sequestration (FRESCOS) Tool. The FRESCOS Tool can be used for project carbon accounting on an annual or scenario basis.

This methodology has been developed and harmonized between the four involved European Development Financial Institutions (EDFI): the Finnish Fund for Industrial Cooperation Ltd (Finnfund), the Dutch entrepreneurial development bank (FMO), CDC Group plc and Swedfund International AB. The technical development of the methodology and the FRESCOS Tool was carried out by Simosol Oy. Specialists from Fortiko were consulted for the design of the agroforestry model and peer-review of the methodology.

The greenhouse gas (GHG) impact of forest project activity is largely based on forests' ability to naturally sequester carbon dioxide (CO_2) and store carbon (C) from the atmosphere. In Box 1, an introduction is given to the forest carbon cycle. It describes some important terms used in the tool as well as the most important carbon pools in the extended forestry system: aboveground biomass (AGB), belowground biomass (BGB), dead organic matter (DOM), soil organic matter (SOM) and harvested wood products (HWP).

Box 1: Forest carbon cycle

CO_2 from the atmosphere is sequestered by living trees through natural tree growth. The sequestered CO_2 represents a GHG removal[4] as it decreases the greenhouse gas concentration in the atmosphere. During the process of photosynthesis CO_2 is converted into oxygen and fixed as carbon in organic compounds i.e., biomass.

Through the process of photosynthesis, the living biomass forms the input of the forest carbon cycle. The biomass growth is allocated to the above and belowground parts of the tree. Dead wood, branches, leaves, needles and other litter form the carbon flux from aboveground biomass (AGB) to dead organic matter (DOM) carbon stock which in turn feeds the soil carbon stock. DOM also comes from belowground biomass (BGB) through root mortality.

Soil organic matter (SOM) consists of fine live and dead roots, and other dead organic matter within the soil that cannot be visually distinguished (see the difference between SOM and DOM from the Glossary). Soils form an important carbon stock which can degrade significantly through human activities. Degradation can take place, for example, through soil preparation, where soil organic carbon previously under anaerobic conditions is brought to aerobic conditions. The available oxygen allows efficient decomposition to take place, resulting in a carbon flux from the soil organic matter back to the atmosphere.

[4] In this document the natural process of removing atmospheric carbon is from here on referred to as *carbon sequestration*. Once removed from the atmosphere by trees, carbon remains *sequestered* in different biological carbon pools for a varying period of time.

Similarly to soil preparation, harvesting permanently removes carbon from the forest carbon cycle. Some of the removed carbon is transferred into harvested wood products (HWP) carbon stock. Carbon remains in wood products for a varying period of time, depending on the product life-cycle. After disposal of wood material by combustion, carbon is emitted back to the atmosphere in the form of CO_2. In addition, in the broader forestry context, including processing and manufacturing of HWP, CO_2 emissions arise from fuel combustion along the wood production chain (Figure 1). The most significant sources of emissions are forest operations, transportation and manufacturing although they are commonly marginal compared to changes in the forest carbon pools.

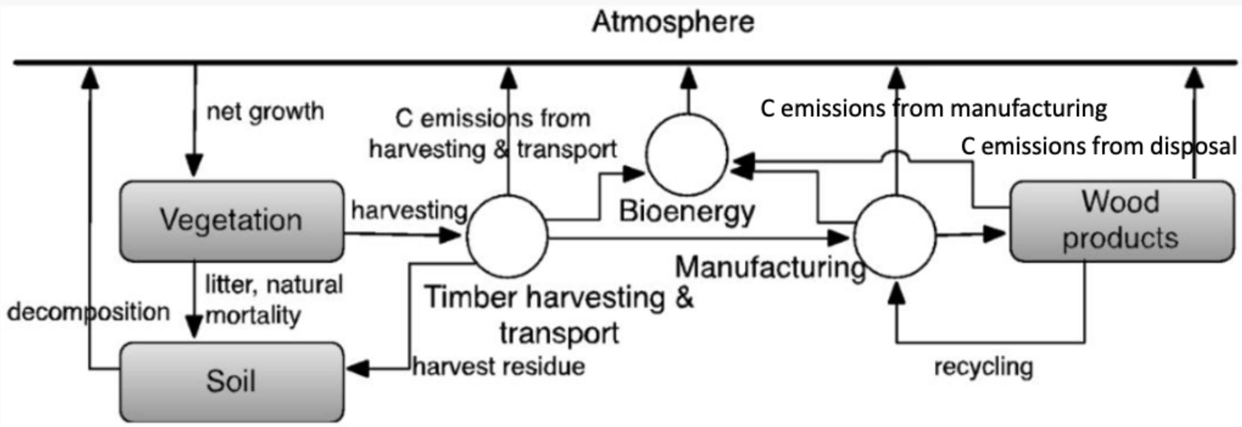

Figure 1. Description of carbon fluxes in the extended forestry system (orig. Liski et al. 2001[5])

An example of the forest and HWP carbon stock development is shown in Figure 2. The stock value indicates the cumulative amount of sequestered carbon that is stored in the extended forestry system over time. The difference in a carbon stock between consequent years is the net carbon sequestration (increasing stock) or emission (decreasing stock). The graph shows that for this example, the total carbon stock in living biomass is expected to grow from 2020 to 2025. Harvesting will commence in 2023 and intensifies in the following years. As a result, the carbon in the harvested wood products increases while the carbon in the living biomass stabilizes.

[5] Liski et al. 2010. Which rotation length is favourable for carbon sequestration? Canadian Journal of Forest Research 31(11):2004-2013

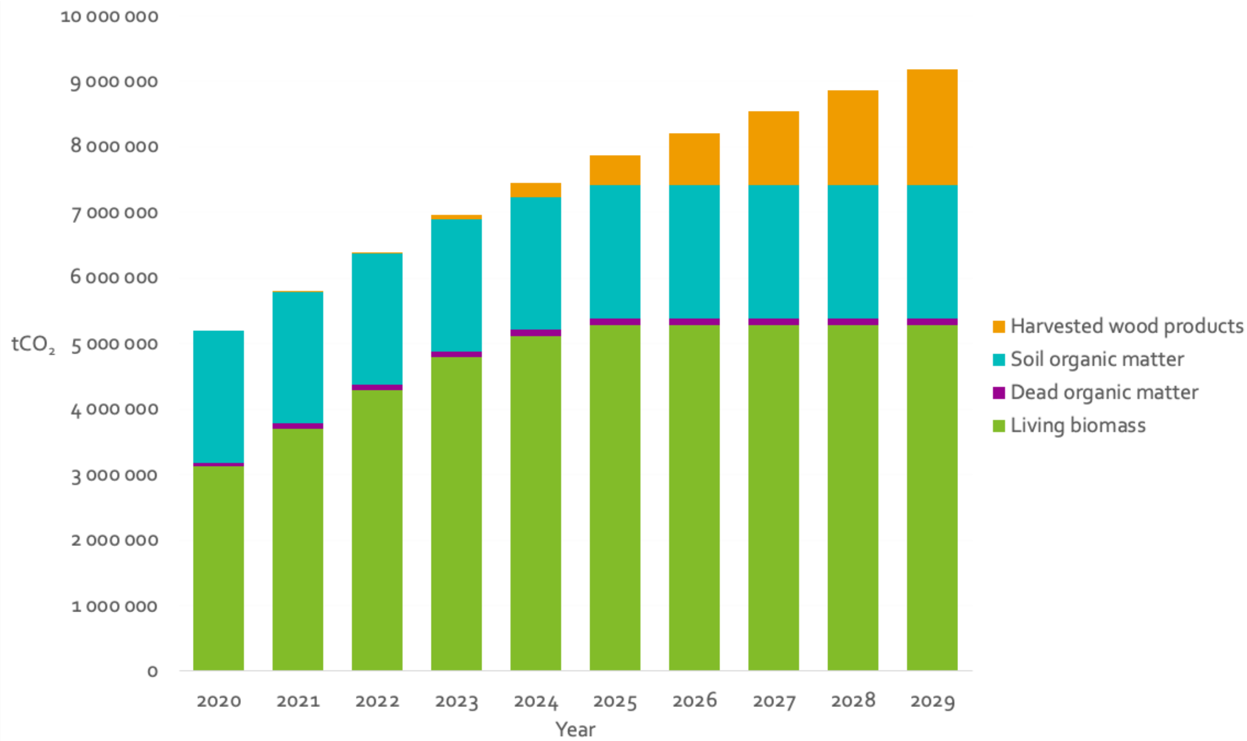

Figure 2. An example of the development of carbon stocks in the extended forestry system

In the AFOLU sector many processes leading to carbon sequestration and emissions can be widely dispersed in space and highly variable in time (IPCC, 2006; p. 1.4) effecting the management of natural resources. In addition, forests are subject to unpredictable anthropogenic actions and natural stress. For example, illegal logging, a forest fire, or a pest outbreak can unexpectedly reverse the estimated carbon flux turning the sustainably managed forest from a carbon sink to a source of emissions. A carbon inventory does not address the permanence or possible revisability of carbon stocks. However, in FRESCOS, the direct impacts of certain known uncertainties can be incorporated and estimated with the 'disturbance rate' parameter.

2. OVERVIEW OF THE APPLIED METHODOLOGICAL GUIDELINES

In the FRESCOS Tool, carbon stocks and changes in stocks in biological carbon pools are estimated by following the guidelines provided by the IPCC. The FRESCOS Tool methodology is built upon the 2006 IPCC Guidelines for National GHG Inventories (2006), which provides internationally agreed methodologies for conducting GHG inventories. The tool applies the most recent Agriculture, Forestry and Other Land Use (AFOLU) methods in the IPCC Guidelines along with the newest refinement from 2019 (IPCC, 2019)[6].

2.1. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (AFOLU)[7]

The IPCC AFOLU Volume 4 ('*the IPCC Guidelines*') provides guidance for preparing annual GHG inventories for six land-use and management categories ('*land-use category*'): Forest Land, Cropland, Grassland, Wetland, Settlement and Other land use (see Figure 3). In addition to forest plantations, Forest Land also includes protected natural forests and forests established and/or managed for recreational purposes. Agroforestry, including trees and perennial crops, is included in the land-use category Cropland. Within Volume 4, guidelines for GHG inventory in Forest Land and Cropland are described separately in Chapters 4 and 5. The Generic Methodologies Applicable for Multiple Land-use Categories are described in Chapter 2.

Each land-use category consists of two sub-divisions: land remaining in that category ('*remaining land*') and land converted from one land-use category to another ('*converted land'*). Land area is advised to be reported as converted land, if the *land-use category* has changed within the last 20 years. This is because a change in the land-use category can have a significant impact on the forest carbon cycle if, for example, existing biomass in cleared and/or soil is prepared prior to planting. It should be noted that conversion here refers to *the change in the given six land-use categories* - land is not considered converted if annual crop production is replaced with an agroforestry system as they both fall under the Cropland land-use category. Typical conversions might occur, for example, from converting degraded grasslands (Grassland) into forest plantations (Forest Land). If the land use prior to current Forest Land or Cropland is not known, land should be assumed as remaining land.

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[6] IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: AFOLU
[7] IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: AFOLU

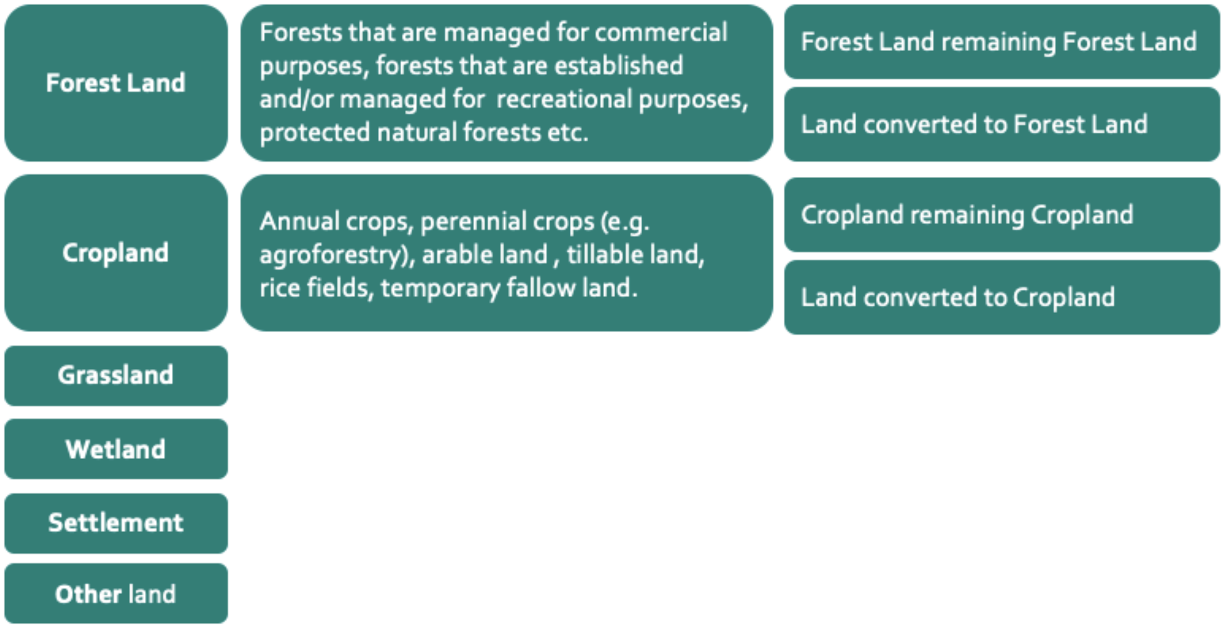

Figure 3. The highest stratification levels in the AFOLU sector according to the IPCC Guidelines

3. METHODOLOGICAL SCOPE

The key GHGs in the AFOLU sector are methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), of which the latter is primarily controlled by the living plants. The non-CO_2 emissions are largely a product of microbiological processes and combustion of organic materials. The calculation in the FRESCOS Tool is limited to ecosystem carbon (C) stock changes as they are predominantly through CO_2 exchange between the land surface and the atmosphere (IPCC, 2006; p. 1.6).

The land-use categories included in this methodology are Forest Land and Cropland. Following the IPCC Guidelines for GHG inventory for these categories (Equation 1), the FRESCOS Tool includes calculation of annual changes and total cumulative carbon stocks in living biomass (above and below ground), dead organic matter (dead wood and litter), soil organic matter and harvested wood products.

Equation 1.

$$\Delta CO_{2\text{-}LU} = (\Delta C_{AGB} + \Delta C_{BGB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SOM} + \Delta C_{HWP}) \cdot CC \qquad (1)$$

Where,

$\Delta CO_{2\text{-}LU}$ = carbon stock changes for a stratum of a land-use category

Subscripts refer to the following carbon stocks:

AGB = aboveground biomass
BGB = belowground biomass
DW = dead wood
LI = litter
SOM = soil organic matter
HWP = harvested wood products

CC = carbon conversion factor

Equation 1. is used for combining the net changes in all carbon stocks from the included land-use categories. The methodology considers perennial[8] woody biomass and organic carbon exclusively, as:

- The increase in biomass in perennial herbaceous (i.e., non-woody biomass) and annual crops in a single year is assumed to be countered by biomass losses from harvest and mortality in that same year (IPCC, 2006; p. 5.7). Thus, there is no net accumulation of carbon in other than perennial woody biomass.
- Scientific data on inorganic carbon is limited. Furthermore, the impact of land management to inorganic carbon stock is smaller than to organic carbon (IPCC, 2006; p. 2.29).

[8] Perennial is a plant whose aboveground parts live for more than two years

4. General methodological considerations

4.1. General calculation approach

The IPCC Guidelines provide instructions for two alternative methods for estimating changes in carbon stocks (ΔC in Equation 1): the *stock-change methodology* (Equation 2) and the *gain-loss methodology* (Equation 3). The gain-loss approach tracks annual changes without accounting for the development of the stock itself. The annual stock change, however, is the difference between measured carbon stocks (c_{t2} and c_{t1}) at two points in time (t_2 and t_1). It should be noted that *measurements* can refer to either 1) direct measurement, or 2) estimation of carbon sequestration and emissions by calculations. The FRESCOS Tool applies the latter for the selected stock-change approach.

Equations 2 and 3.

$$\Delta C = (C_{t2} - C_{t1})/(t_2 - t_1) \quad (2)$$

Where,

ΔC	= carbon stock at any given time, tC
C_{t2}	= carbon stock in the pool at time t_2, tC
C_{t1}	= carbon stock in the pool at time t_1, tC

$$\Delta C = \Delta C_G - \Delta C_L \quad (3)$$

Where,

ΔC	= carbon stock at any given time, tC
ΔC_G	= annual gain of carbon, tC
ΔC_L	= annual loss of carbon, tC

The FRESCOS Tool enables the implementation of a lower and a higher level of accuracy. The two options follow the general principles of the IPCC Tiers 1,2 and 3 (see a more detailed description below in Box 2). As opposed to the IPCC Guidelines, where the level of accuracy is selected separately for each carbon pool, in the FRESCOS Tool it is done at project level. A more detailed description of the calculation process in the FRESCOS Tool for different carbon stocks is described in the following chapter.

Box 2: IPCC Tiers

In the IPCC Guidelines the estimation of carbon stocks and changes in stocks can be undertaken by using different levels of accuracy and certainty (Tiers). Tiers can also dictate the inclusion or exclusion of specific carbon stocks in the GHG inventory. For example, in Tier 1 approach the DOM stock is assumed not to be present in land-use categories other than Forest Land. Likewise, under Tier 1 approach it is assumed that soil organic carbon remains stable with management. These assumptions are not exactly accurate but estimating the actual carbon stocks in dead organic matter and soil would require detailed and locally representative data, which is usually absent. Such simplified assumptions may not always reflect the exact reality, but they are critical for enabling calculations with limited data. In general terms, Tier 1 relies on the IPCC default values whereas country-specific data is needed for Tier 2. The tool user should recognize that the IPCC default values are global estimates based on broad geographic assumptions. The variation or the uncertainty of these assumptions is commonly indicated separately for each given default value in the IPCC tables (see Annex 2-6). Tier 3 requires project-specific data that is in forestry projects commonly available for biomass carbon pool only.

Increasing the level of certainty will simultaneously increase the methodological complexity through improved localization of model parameters, spatial resolution and increased extent of required data. Therefore, the selection of the appropriate Tier requires an assessment of costs and efficiency in relation to relevant data acquisition. In addition, the selection of the desired level of accuracy should consider the objective of the assessment and the requirements to meet the objective.

4.2. Annual accounting and scenario analysis

The methodology applied in the FRESCOS Tool can be implemented for estimating project's carbon sequestration and emissions as *annual accounting* and as *scenario analysis*. The outputs of the annual accounting are provided for current carbon stocks and their annual change, whereas the scenario analysis estimates the development of the carbon stocks over a longer time frame. The scenario analysis feature can also be used for estimating historical development by inserting historical data as an input, e.g., replacing planned planting areas with the historical development of the planted area. The specific time frame for the scenario analysis is set by the user in the FRESCOS Tool.

Notably, the scenario analysis in the FRESCOS Tool does not address the permanence of the estimated carbon stocks during the assessment period beyond those incorporated in the user inputs. Estimation of the longevity and possible reversibility of the carbon flux, or estimation of likelihoods for such unexpected events to occur, requires additional analysis outside of the FRESCOS Tool. Likewise, carbon leakage considerations are not included in the scope of the FRESCOS methodology.

5. CALCULATION IN THE FRESCOS TOOL

The technical calculation methodologies applied in the FRESCOS Tool for the included carbon pools; living biomass, soil organic matter, dead organic matter and the harvested wood products (Equation 1), are described in this chapter. The calculations are based on the general considerations outlined in the previous chapter. As noted before, the methodology follows the general principles of the IPCC Tiers, most importantly the following: Tier 1 relies on global default values, Tier 2 uses regional or national data and Tier 3 requires project-specific data. A summary of the applied IPCC tiered approach for carbon modelling in forestry and agroforestry project is provided in Table 1.

As noted, in FRESCOS the level of accuracy is set on project level. In practice, it is defined by the inputs for the biomass pool for which both Tier 3 and Tier 1 calculations are supported in the tool. This means that in the FRESCOS Tool the higher level of accuracy includes a combination of the applicable IPCC Tier 1, 2 and 3 methodologies, depending on land-use classes and different carbon pools (Table 2).

Table 1. The tiered IPCC methodologies applied in the FRESCOS Tool for different carbon pools

Included carbon pool	IPCC Tier 3	IPCC Tier 2	IPCC Tier 1
Living biomass	Stock is estimated separately for each stratum based on the planting year. Stock change: The difference between the modelled biomass growth and estimated losses. Biomass growth (G_w) is estimated combining information on the mean annual increment (MAI), with biomass expansion factors (BEF) and root-to-shoot ratios (R). Biomass losses (L) are accounted for due to harvesting, disturbances, and possible land-use conversion.	N/A	Stock is estimated with IPCC default values for AGB. Stock change is the difference between IPCC default values for the mean AGB growth (G_w) and total biomass losses (incl. disturbances and possible land-use conversion)
Dead organic matter (DOM)	N/A	N/A	Stock and change in stock are estimated with CDM[9] default values for dead wood and litter stocks as a share of the AGB stock.
Soil organic matter (SOM)	N/A	N/A	Stock is estimated with IPCC default values. Stock change is considered only for converted land and drained organic soils for which IPCC default values exist.
Harvested wood	N/A	Stock and stock change are calculated	N/A

[9] Clean Development Mechanism (UNFCCC). A/R Methodological tool (AR-TOOL12)

products (HWP)	based on reported allocation to semi-finished commodities and default IPCC half-life values.

Table 2. The application of the IPCC Tiers at the two accuracy levels of the FRESCOS Tool

Carbon pool	Higher level of accuracy	Lower level of accuracy
Biomass	Tier 3	Tier 1
Dead organic matter	Tier 1	Tier 1
Soil organic matter	Tier 1	Tier 1
Harvested wood products	Tier 2	N/A

The included carbon stocks are estimated similarly in forestry and agroforestry projects unless otherwise stated. When applicable in the FRESCOS Tool, the methodologies in this document are described separately for each applied Tier as they differ in data requirements:

1. The required project-specific inputs used under Tier 3 should be identified and inserted to the tool by the user. Following the Tier 3 approach, the tool user is required to insert all data related to biomass calculations per stratum. This means that forestry project areas should be subdivided into smaller sections (strata) according to tree species, area, planting year, mean annual increment, rotation length and disturbance rate. An example of stratification is shown in Table 3.

Table 3. Example of the stand level stratification in the FRESCOS Tool

2. Forest plantations

1. Summary | 2. Forest plantations | 3. Agroforestry | 4. HWP | 5. Natural forests and other | 6. Results

ADD ROW

Land use category	Tree species	Area (ha)	Planting year	MAI (m^3/ha/a)	Harvest cycle (years)	Disturbance rate	Year of land-use conversion	Previous AGB stock (t/ha)	Soil class	Soil carbon stock (tC/ha)
Forest Land	Eucalyptus pellita	615	2011	12	7	0			HAC - High Activity soils	60
Forest Land	Eucalyptus pellita	9	2010	12	7	0			HAC - High Activity soils	60
Forest Land	Eucalyptus pellita	874	2012	12.8	7	0			HAC - High Activity soils	60
Forest Land	Eucalyptus pellita	530	2013	9.4	7	0			HAC - High Activity soils	60

2. For calculations under Tier 1, global IPCC default values (from IPCC, 2006 and 2019) are integrated into the tool. User inputs are needed on the reported climate zone, continent, region, land-use class, soil class and land areas. Other than the aforementioned inputs, no additional inputs are required under calculations at the lower level of accuracy.

A summary of the inputs, required to be set by the FRESCOS tool user, is presented in Table 4 separately for the higher and the lower level of accuracy.

Table 4. Summary of the input data sources and the minimum required inputs in the FRESCOS Tool

Input	Higher level of accuracy	Lower level of accuracy
Climate zone	Predefined list (IPCC)	Predefined list (IPCC)
Continent	Predefined list (IPCC)	Predefined list (IPCC)
Living biomass	Project specific reference values: species, land area, MAI, planting year and harvest cycle and disturbance rate by stratum	Predefined list (IPCC) and project specific reference values: disturbance rate, land area
SOM	Predefined list (IPCC)	Predefined list (IPCC)
Converted land	Predefined list (IPCC)	Predefined list (IPCC)
HWP	Project specific reference values: total harvested roundwood, allocation to product categories	N/A

The impact of land-use conversion that has occurred within the past 20 years is included in the FRESCOS Tool and described in more detail in the following sections. If the previous land-use category is unknown, the land area can be considered as remaining land.

5.1. Carbon pool in living biomass

Biomass growth is allocated in both the aboveground and belowground parts of the tree. In forestry, the commercial part of the tree (i.e., the trunk) is most often of interest. Consequently, most forest growth models and data (mean annual increment (MAI) values and harvested volumes) account only for the tree trunk and its growth. As carbon in biomass is stored not only in the trunk but also in roots, branches, tree top, leaves and needles, biomass carbon modelling requires the expansion of existing biomass data to include the total biomass. Similarly, in order to account for the total loss in living biomass due to harvesting, harvested commercial volumes are expanded to include also non-merchantable parts of the tree.

The net impact of biomass growth indicates the net carbon sequestration in living biomass during the assessment period. The impact of biomass is positive, i.e., carbon net sequestration occurs, if biomass losses due to harvesting and disturbances do not exceed the biomass gains resulting from biological growth.

5.1.1. Tier 3 change in living biomass carbon pool

This section describes in detail the applied inputs and assumptions for calculating the net carbon impact of the living biomass carbon pool under the higher level of accuracy in the FRESCOS Tool. The calculation logic follows that of the IPCC Tier 3 methodology for forest biomass. The applied equations are presented at the end of this section in Box 3.

The existing carbon stock in living biomass (C_B) will be estimated per stratum based on the reported planting year and the mean annual increment (MAI). The stratum-level results are summed in order to estimate the total stock (Equation 4).

Annual change in biomass carbon stock (ΔC_B) consists of carbon gains resulting from natural growth (G_{TOTAL}) and carbon losses (L_{TOTAL}) due to harvesting and disturbances (Equation 5).

Total biomass growth (G_{TOTAL}) will be modelled implicitly based on the mean annual increment (MAI, m^3/ha) values, which indicate the annual growth rate of the merchantable volume of a certain tree-species. MAI values are combined with the relevant land area (ha) in order to estimate the total annual increment volume (I_V) in Equation 6. The modelled increment volume is first converted to growing stock biomass growth by weighing the volume with the tree species-specific basic density value (D). The obtained value for growing stock biomass does not include living biomass in tree tops, branches, foliage and other non-merchantable components. The growing stock biomass is hence further expanded to total AGB by applying a tree species-specific biomass expansion factor (BEF). The BGB is estimated as the share of the aboveground biomass with a root-to-shoot (R) ratio. The AGB and the BGB form the total living biomass as calculated according to Equation 4.

An example of the correlation between the BEF and R values as well as biomass allocation between the tree parts (merchantable volume, branches, leaves, tree top and live roots) is given in Figure 4.

Figure 4. Example of biomass allocation within the living parts of the tree

Some BEF and R values are provided in the FRESCOS Tool by default. Custom BEF and R values can also be sought from existing literature when adding new tree species or adjusting the parameters of the existing species. Relevant studies can be browsed, for example, from the GlobAllomeTree database.

The total annual biomass loss (L_{TOTAL}) is the sum of losses from wood removal ($L_{wood-removals}$) and losses due to disturbances ($L_{disturbance}$) (Equation 7). The annual losses in biomass pool due to harvested removal (H) (m^3/a) are derived from the reported annual harvest volumes. Rotation length by stratum is required from the tool user as it is used to allocate the harvested volumes according to tree species and stand maturity. Optionally in the FRESCOS Tool annual harvest volumes can be generated automatically based on the reported rotation cycle. The annual harvested volumes are similarly expanded and converted to total biomass removal (incl. AGB and BGB) by applying relevant D, BEF and R values as presented in Equation 8. Note that the impact of wood removals is not limited to AGB although wood removed from the forest might only explicitly include aboveground parts. The remaining biomass belowground will start to decay after harvesting and is hence removed from the BGB carbon stock. Though in practice a share of the AGB and BGB of the harvested trees goes into DOM and SOM pools, the applied methodology assumes these explicitly as permanent removals. Calculation of DOM and SOM pools are described under their own sections. $L_{wood-removals}$ is allocated to energy production and HWP pool based on the inserted product allocation.

Other annual losses in total living biomass due to disturbances ($L_{disturbance}$) (caused by mortality, wind, fire etc.) should be considered implicitly in the reported value for the disturbance rate (d). The disturbance rate should indicate the share of the standing stock that is lost annually due to disturbances (%/ha/a) (Equation 9).

Change in biomass carbon stock in land areas that have gone through conversion within the last 20 years are estimated similarly as described above (Equation 6 and 7). In addition, the initial change in living biomass for the moment of land conversion is required to be included in carbon losses (L_{TOTAL}) under Tier 3. The initial change is estimated as a difference between biomass stock before conversion and biomass stock immediately after in order to account for the possible losses due to change in land-use category (for example Cropland converted to Forest Land). In practice, the initial change in biomass is the amount of biomass that was possibly cleared from the land that was converted to Forest Land or Cropland. Reference values for the AGB stock in Cropland and Forest Land are provided in Annexes 2, 3 and 4, respectively. The initial change in living biomass carbon stock will be accounted for in the overall net carbon impact of the project.

> For example, the maximum AGB carbon stock in a Silvopasture system in the Temperate climate zone is 69.9 tC/ha (Annex 2) - if an area of 30 hectares is cleared from biomass and converted to another land-use category (for example, Forest Land), the initial change in biomass carbon stock is 69.9 tC/ha · 30 ha = 2 097 tC = 7 689 tCO_2

The initial decrease is accounted for as a baseline carbon stock which is subtracted from the project carbon stocks for estimation of the net carbon impact. Consequently, the cleared biomass does contribute to annual biomass stock change, but it is simply reduced from the existing biomass carbon stock.

Box 3: Equations for estimating carbon in biomass (Tier 3)

$$C_B = \sum\{a \cdot MAI \cdot A \cdot D \cdot BEF \cdot (1+R)\} \cdot CF \quad (4)$$

Where,

C_B = total carbon stock in living biomass, tC
a = stand age, years
MAI = mean annual increment, m^3/ha/a
A = stratified land area, ha
D = basic wood density, t/m^3
BEF = biomass expansion factor, dimensionless
R = ratio of BGB to AGB for a specific vegetation type, dimensionless
CF = carbon fraction of dry matter, tC (IPCC, 2006; Table 4.3)

$$\Delta C_B = (G_{TOTAL} - L_{TOTAL}) \cdot CF \quad (5)$$

Where,

ΔC_B = total annual change in biomass carbon stock, tC/a
G_{TOTAL} = total annual biomass gains (Equation 6), t/a
L_{TOTAL} = total annual biomass losses (Equation 7), t/a
CF = carbon fraction of dry matter, tC (IPCC, 2006; Table 4.3)

$$G_{TOTAL} = \sum\{I_V \cdot D \cdot BEF \cdot (1 + R)\} \quad (6)$$

Where,

G_{TOTAL} = total annual biomass growth, t/a
I_V = annual increment for specific tree species by stratum, m^3/ha/a
D = basic wood density, t/m^3
BEF = biomass expansion factor, dimensionless
R = ratio of BGB to AGB for a specific vegetation type, dimensionless

$$L_{TOTAL} = L_{wood-removals} + L_{disturbance} \quad (7)$$

Where,

L_{TOTAL} = total annual biomass losses, t/a
$L_{wood-removals}$ = annual losses due to log wood removal (Equation 8), t/a
$L_{disturbance}$ = annual losses in living biomass due to disturbances (Equation 9), t/a

$$L_{wood-removals} = H \cdot D \cdot BEF \cdot (1+R) \quad (8)$$

Where,

$L_{wood-removal}$ = annual losses due to roundwood wood removal, t/a
H = annual wood removals, roundwood or fuel wood, m^3/a
D = basic wood density, t/m^3 (IPCC, 2006; Table 4.13)
BEF = biomass expansion factor , dimensionless
R = ratio of BGB to AGB for a specific vegetation type, dimensionless

$$L_{disturbance} = \sum(A \cdot B \cdot d) \quad (9)$$

Where,

$L_{disturbance}$	= total losses due to disturbances (mortality, fire, wind etc.), t/a
A	= stratified land area, ha
B	= standing stock biomass per strata, t/a
d	= disturbance rate, factor value

5.1.2. Tier 1 change in living biomass carbon pool

This section describes in detail the applied inputs and assumptions for calculation of net carbon impact for the living biomass carbon pool under the lower lever of accuracy in the FRESCOS Tool. The calculation logic follows that of the IPCC Tier 1 methodology for forest biomass. The applied equations are presented at the end of this section in Box 4. The Tier 1 approach can be used, for example, for estimating carbon stocks in conservation areas where the woody vegetation and other input required for Tier 3 calculations are unknown or not available.

Existing carbon stock in living biomass will be estimated with IPCC default reference levels for AGB biomass (AGB_{REF}) in natural forests and forest plantations (Annex 4) and biomass in agroforestry systems containing perennial species (Annex 2 and Annex 3). Similar to Tier 3, the total existing carbon stock consists of carbon stocks in separate strata or larger areas.

Change in stock is, similarly to Tier 3, the difference between annual biomass gains and losses (Equation 5). The IPCC default values for the average annual AGB growth for a specific woody vegetation type (G_W) are used to estimate the change in living biomass (Equation 11). The reference AGB stock values are given at the maximum level (Annex 2 to 4). They are linked to a default harvest or maturity cycle ('*cycle*') that indicates the saturation point of the stock. The AGB stock will hence increase linearly over the given cycle until it reaches the reference stock level. At the end of the cycle the biomass stock will only change by the reported rate of disturbance. Losses due to disturbances are estimated similarly as applied under Tier 3 (Equation 9).

Default IPCC root-to-shoot ratios (R) are provided according to climate zone and continent. In order to follow the principle of conservativeness, the suggested R values in the FRESCOS Tool represent minimum values provided by the IPCC for the specific climate zone and continent. In the absence of relevant R values, belowground biomass stock is excluded.

Estimation of the initial change in biomass due to land-use conversion is not required for Tier 1 in land converted to Forest Land (IPCC, 2006; p. 4.32). Because land conversion to Cropland is more likely to cause significant changes in the existing biomass, the initial change should be reported also under Tier 1 for converted Cropland only. The impact of conversion to the initial biomass carbon stock is estimated similarly as described in the example for Tier 3. Accordingly, the initial decrease is accounted for as a baseline carbon stock which is subtracted from the project carbon stocks for estimation of the net carbon impact.

Both in Forest Land and Cropland, biomass stock right after conversion is assumed to be zero and to develop linearly until the reference level is reached. In converted Forest Land the reference level will be reached after the default period of 20 years, whereas in Cropland the default maturity cycle varies among tree species.

An example of biomass carbon stock development, without any disturbance, in Forest Land and Cropland is given in Figure 5. In the example, land conversion took place in 1995. Biomass carbon stock in the new tea plantation (Cropland) will reach the given maximum AGB level of 20.7 tC/ha (Annex 3) by the end of the 30-year harvest cycle in 2025 after which it will remain stable. The Tropical moist deciduous forest (Forest Land) will reach the default AGB level of 31.8 tC/ha and saturation point after 20 years from conversion in 2015. Both areas are considered remaining land after 2015 when 20 years since conversion has passed.

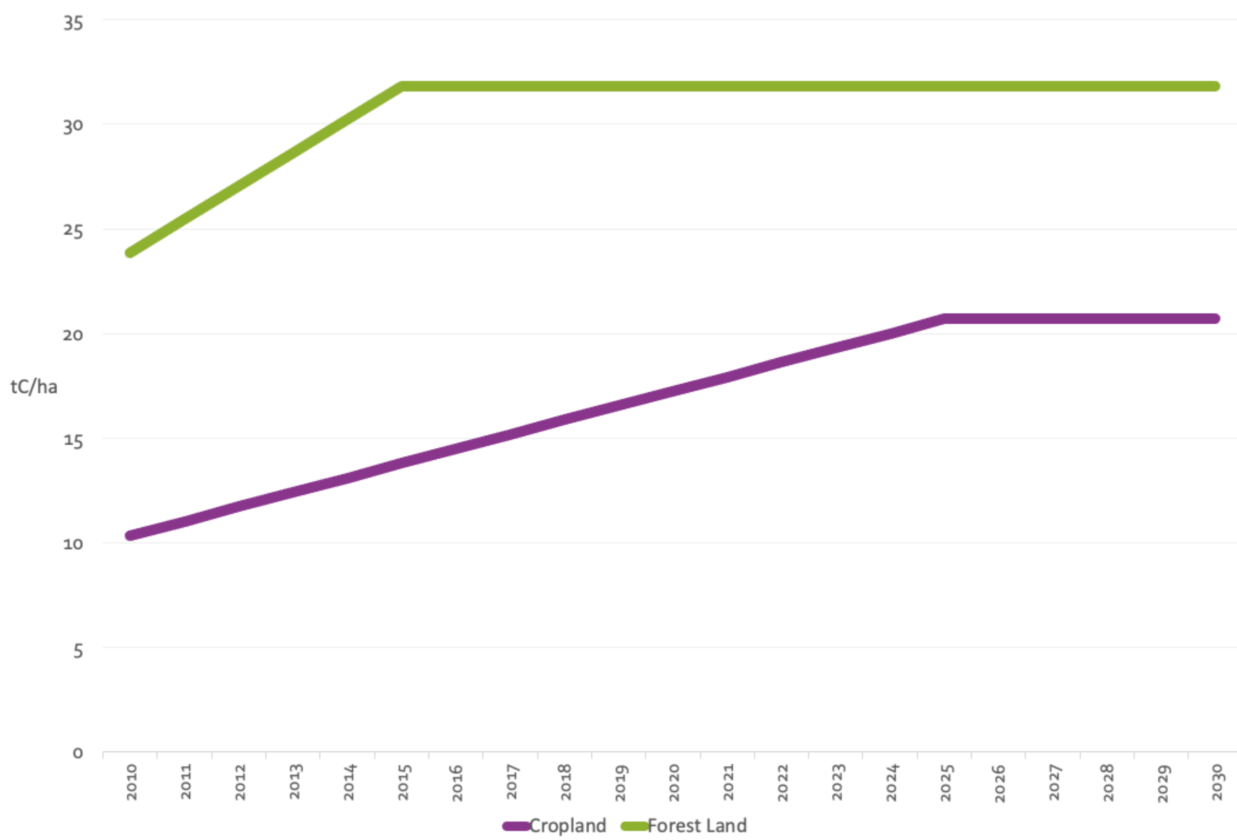

Figure 5. Biomass carbon stock development 15 years after conversion

Box 4: Equations for estimating carbon in biomass (Tier 1)

$$C_B = \sum(A \cdot AGB_{REF}) \cdot (1+R) \cdot CF \quad (10)$$

Where,

C_B	= total carbon stock in living biomass, tC
A	= stratified land area, ha
AGB_{REF}	= aboveground biomass in a given land-use category (Annexes 2, 3 and 4), t/ha
R	= ratio of BGB to AGB for a specific vegetation type, dimensionless (based on IPCC, 2019; Table 4.4)
CF	= carbon fraction of dry matter, tC (IPCC, 2006; Table 4.3)

$$G_{TOTAL} = \sum\{G_W \cdot (1+R)\} \quad (11)$$

Where,

G_{TOTAL}	= total annual biomass growth in remaining land, t/a
G_W	= average annual AGB growth (Annexes 2, 3 and 4), t/ha/a
R	= ratio of BGB to AGB for a specific vegetation type, dimensionless (based on IPCC, 2019; Table 4.4))

Note: In converted land, carbon stock in living biomass will increase linearly and reach the reference level (AGB_{REF}) after the given maturity cycle or after 20 years from the conversion.

5.2. Carbon pool in soil organic matter

The soil organic matter forms an important carbon reservoir in the forest carbon cycle. In theory, a SOM stock increase represents a decrease in the DOM stock, which is not emitted back to the atmosphere but merely transferred from one carbon pool to another. The stock value itself is an important measure that indicates the amount of the sequestered carbon still within the forest carbon cycle. In forestry, major changes in SOM stock are commonly emissions due to management activities that accelerate soil carbon decay.

In general, the net change of soil organic carbon consists of carbon gains through litter and dead wood decomposition, and carbon losses due to decay. The annual net change of soil organic matter is positive if the emissions from decay do not exceed the carbon gains from litter and dead wood production. However, modelling of these processes requires sophisticated inputs and obtaining these inputs is not considered realistic within the scope of the FRESCOS Tool. Therefore, soil organic carbon stock changes are calculated only in case of land use conversion and for drained organic soils[10] for which applicable IPCC default values are provided.

The applied methodology for calculating changes in soil organic carbon stocks is limited to Tier 1 approach, with the possibility to improve accuracy by replacing IPCC default soil carbon reference values with manual user inputs. Such inputs can potentially be identified, for example, from national soil databases or scientific literature. Certain projects might even have carried out their own soil sample measurements, including the organic carbon content.

5.2.1. Tier 1 change in soil organic carbon pool

This section describes in detail the applied inputs and assumptions for calculation of soil organic carbon stocks and their changes at both accuracy levels in the FRESCOS Tool. The applied equations are presented at the end of this section in Box 5.

Soil carbon stock (C_S) is estimated by implementing Equation 12. The stratum-level results are summed in order to estimate the total stock at the project level.

The IPCC reference values (Annex 5) for carbon densities (tC/ha) on mineral soils ($REF_{M.SOI}$) in specific climate regions and soil types are applied directly on Tier 1 level (Equation 12). The Tier 1 method assumes that forest soil carbon stock does not change with management (IPCC, 2004; p. 4.23). In Tier 1, the actual carbon stocks in drained organic soils are excluded due to data limitations (IPCC, 2006; p. 4.24). Annual carbon stock change in drained organic soils, however, is estimated with IPCC's CO_2 emission factors ($\Delta C_{O.SOIL}$) by land-use category and climate/vegetation zone (Annex 6). The emission factors are multiplied with stratified land areas in order to estimate the total emissions (Equation 13).

Changes in soil carbon due to possible land conversion are considered implicitly within the built-in soil calculations quite similarly to the AGB in converted land: the stock is assumed to grow from the initial level prior to conversion and reach the selected reference level within 20 years. The initial soil carbon stock is determined automatically based on the previous management activities which are set by selecting the land-use, management and input levels from the given IPCC default options in the FRESCOS Tool. The impact of separate management activities in previous Cropland and Grassland is determined with the built-in soil stock change factors (Annex 9). An example of the required soil inputs in converted land is given in Annex 1 where the use of the FRESCOS Tool is illustrated in general.

[10] Organic soils can be drained in order to improve growing conditions. The wet conditions in soil enable the accumulation of significant amounts of carbon, which starts to increasingly release when the soil water table level drops below natural levels (see Box 1. for description of soil carbon dynamics).

Box 5: Equation for estimating carbon in SOM (Tier 1)

$$C_S = \sum(REF \cdot A) \quad (12)$$

Where,

C_S = total carbon stock in soil organic matter, tC
REF = reference level of soil organic carbon (Annex 5), tC/ha
A = stratified land area, ha

Note: In converted land, the reference level is reached after 20 years from the conversion after which it stabilizes

$$\Delta C_{O.SOIL} = EF \cdot A \quad (13)$$

Where,

$\Delta C_{O.SOIL}$ = total emissions from drained organic soils, tCO_2
EF = IPCC emissions factor for drainer organic soil (Annex 6), tCO_2/ha
A = stratified land area, ha

5.3. Carbon pool in dead organic matter

Similar to SOM, the dead organic matter (DOM) (including dead wood and litter) forms an important carbon stock even though its annual changes are minor. Carbon transfers gradually into the DOM pool from the biomass carbon stock due to, for example, tree growth competition and as harvesting residues (see Box 1. for forest carbon dynamics). As with SOM, the DOM carbon pool acts as an extended storage for sequestered carbon that originates from the living biomass pool.

Accurate estimation of the dead organic matter (DOM) stock change is highly input intensive and complex (see IPCC 2006; Equations 2.14, 2.20, 2.21 and 2.22). It requires direct measurements which can face practical limitations. For Forest Land, the IPCC Guidelines recognize that the default values for estimating the DOM pool are 'broad-scale estimates with considerable uncertainty when applied at the country level' (IPCC, 2019; p.2.26). Considering the project-level application of the FRESCOS Tool, this deficiency of the IPCC default values for DOM is addressed by using default values provided by the Clean Development Mechanism (CDM). The CDM A/R (AR-TOOL12[11]) default values have been developed for estimating carbon stocks in dead wood and litter in afforestation and reforestation project activities, specifically. These values provide an estimation of the DOM stock in correlation with the standing stock biomass. Therefore, also annual changes in the DOM stock are in direct correlation with changes in the living biomass stock. In Cropland areas (agroforestry systems) it is assumed that DOM stock is not present (IPCC, 2006; p. 5.13).

[11]Clean Development Mechanism (UNFCCC). A/R Methodological Tool (AR-TOOL12): Estimation of carbon stocks and changes in carbon stocks in dead wood and litter in A/R CDM project activities .

Notably, DOM calculation in the FRESCOS Tool is consistent with the IPCC Tier 1 estimation due to the use of default factors.

5.3.1. Tier 1 change in dead organic matter carbon pool

DOM carbon stock (C_{DOM}) is estimated by combining separate default factors for the relationship between carbon stock in litter (DF_{LI}) and dead wood (DF_{DW}), with the carbon stock in aboveground biomass (C_{AGB}) (Equation 14).

In the IPCC Guidelines, under Tier 1 the DOM carbon stock is assumed not to change over time (IPCC, 2019; p. 2.20). At both levels of accuracy in the FRESCOS Tool, this assumption is refined so that DOM carbon stock changes are in direct correlation with the changes in the biomass carbon stock. As DOM is assumed not to be present in non-forest land and Forest Land is not likely to be subject to conversion, land-use conversion does not affect the DOM pool (IPCC, 2006; p. 2.9).

Box 6: Equation for estimating carbon in DOM (Tier 1)

$$C_{DOM} = (DF_{LI} \cdot C_{AGB}) + (DF_{DW} \cdot C_{AGB}) \quad (14)$$

Where,

C_{DOM}	= total carbon stock in dead organic matter, tC
DF_{LI}	= default factor for the relationship between carbon stock in litter and carbon stock in living trees, dimensionless (Annex 7, Table 6)
DF_{DW}	= conservative default factor expressing carbon stock in dead wood as a percentage of carbon stock in tree biomass, dimensionless (Annex 7, Table 5)
C_{AGB}	= total carbon in aboveground biomass, tC

Note: As the DOM stock is proportional to the AGB stock, the annual change correlates with the change in the AGB stock.

5.4. Carbon pool in harvested wood products

Total annual harvested volumes are needed to account for carbon flux from living biomass stock to the harvested wood products (HWP) stock.

Estimation of the change in the HWP stock requires information from the tool user on

1. product allocation to the semi-finished HWP commodities (sawnwood, wood-based panels, and paper and paperboard) and energy production, and
2. estimation of the utilization rate of round wood for each wood product category.

The allocation is needed as wood products have different service-lives or life-cycles, i.e. they store carbon for varying periods of time. If project-specific information is not available, national timber production statistics should be used to estimate the product allocation. In order to account for the annual losses in the HWP pool due to decay, half-life values (years) for each semi-finished HWP commodity class are included in the tool. Typically, the allocation to commodity categories is tightly connected with general forest management regime, i.e., selected species, planting density, and harvesting cycle (rotation). Fast growing species, like eucalyptus, are commonly grown on short rotations <10 years) for pulp wood (paper and paperboard) or for bioenergy. Conifers and high-value broadleaves, like teak, are often grown on longer rotations (>20 years) for the production of saw logs or plywood logs.

The utilization rate indicates the share of the extracted round wood that ends up into the actual wood product. Default utilization rates are provided within the FRESCOS Tool; 47.2% for paper and paperboard, 53.7% for wood-based panels, and 43.5% for sawn wood (EFI, 2002[12]). Utilization rates should be adjusted by the user as needed, to better fit the local wood processing conditions of the given forestry project.

The HWP is estimated in terms of the *pool in use* (IPCC, 2019; Equation 12.2) consisting of wood used as a material. In annual accounting only the given year's HWP stock addition is considered, whereas in the scenario analysis the accumulation of the HWP stock over time is included. The developed method for estimating HWP stock change in the FRESCOS Tool (available for the higher level of accuracy exclusively) requires a combination of Tier 2 (project-specific) and Tier 1 (default) level data: in the FRESCOS Tool, the HWP stock is estimated based on project-specific (or country-specific) wood product allocation and default half-life values (Annex 8). All losses from the HWP pool in use are assumed to result in CO_2 emissions without distinguishing the means of disposal (solid wood disposal site or energy production) (IPCC, 2019; p. 12.36).

Harvested wood that is allocated to energy production is excluded from the HWP calculation for the pool in use (IPCC, 2019; p. 12.34). Instead, the CO_2 emissions from biomass harvested for energy production are included implicitly as a decrease in living biomass carbon stock due to fuel wood harvesting (Equation 8).

5.4.1. Tier 2 change in harvested wood product carbon pool

At the higher level of accuracy of the developed FRESCOS methodology, the estimation of carbon stock in each of the semi-finished HWP categories at the end of the year [$C_l(i+1)$] is done by implementing Equation 15 presented in Box 7. The $Inflow_l(i)$ consists of the annual carbon inflow to the particular HWP commodity class (l). The decay constant (k) for the HWP stock is determined with half-life (HL) values separately for each HWP commodity class as [ln(2)/HL]. In annual accounting the stock is defined by the annual inflow - the previously existing stock is assumed to be zero. The impact of annual inflow is calculated in the second term of Equation 15: $\{[(1-e^{-k})/k] \cdot Inflow_l(i)\}$.

The existing HWP carbon stock [$e^{-k} \cdot C_l(i)$] is included when calculating the stock at the end of the year in scenario analysis. There the annual change in HWP stock is estimated according to Equation 16 as the difference between the stock at the beginning of the year (i) and at the end (i+1). The example of HWP

[12] EFI, 2002. The Impacts of Manufacturing and Utilisation of Wood Products on the European Carbon Budget. Eggers, Thies. EFI Internal Report 9.

stock development in Figure 6 shows how the HWP stock increases at the beginning but stabilizes over time, when annual inflow equals to annual decay.

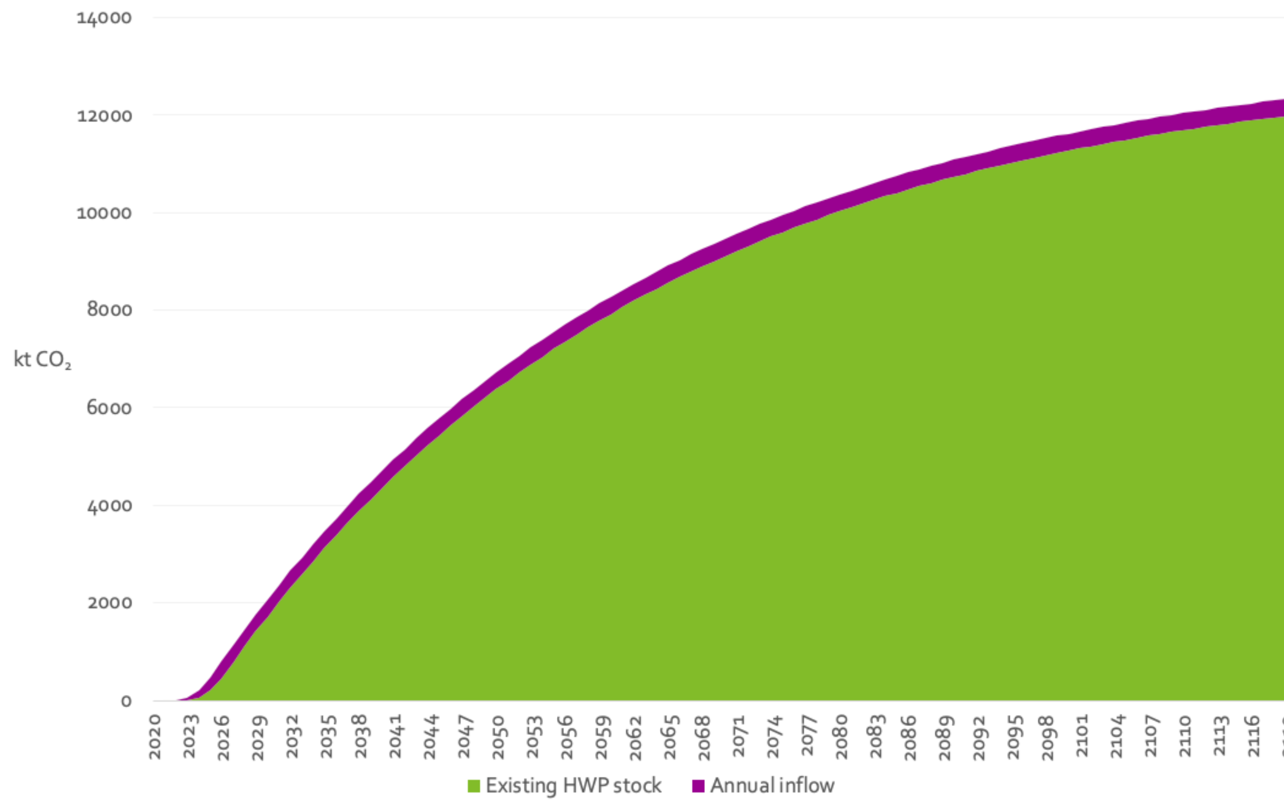

Figure 6. Example of HWP carbon stock development over 100 years

Box 7: Equations for estimating carbon in HWP (Tier 2)

$$C_l(i+1) = e^{-k} \cdot C_l(i) + [(1-e^{-k}) / k] \cdot Inflow_l(i) \qquad (15)$$

Where,

$C_l(i+1)$	= HWP carbon stock in the particular HWP commodity class *l* at the end of the year (i+1), tC
$C_l(i)$	= the carbon stock in the particular HWP commodity class *l* at the beginning of the year (i), tC
k	= decay constant - separately for each HWP commodity class *l* (Annex 8)
$Inflow_l(i)$	= the annual carbon inflow to the particular HWP commodity class *l*, tC/a

Note: The first term $[e^{-k} \cdot C_l(i)]$ accounts for the development of the existing stock, and the latter $\{[(1-e^{-k})/k] \cdot Inflow_l(i)\}$ indicates the annual inflow.

$$\Delta C_l(i) = C_l(i+1)-C_l(i) \qquad (16)$$

Where,

$\Delta C_l(i)$	= annual change in HWP stock in the particular HWP commodity class at the beginning of the year (i+1), tC

5.5. Auxiliary inputs and possible applications of the tool

The results of the FRESCOS Tool can be used for wider analyses for quantification of forest carbon sequestration. Comparison between scenarios is possible by creating parallel projects as alternative scenarios and rerunning the calculations with hypothetical data. The alternative scenario could, for example, represent the carbon impact of deforestation in the same area. In this example the comparison of the project and scenario results would indicate the avoided emissions through project activity. The Tier 1 default values enable the creation of hypothetical scenarios quite effortlessly, and a deforestation rate can be applied as disturbance rate.

The FRESCOS Tool is not designed to supplement any particular GHG program, but it can provide indicative results for several applications. The FRESCOS Tool can, for example, be used as a basis to determine the GHG reduction required by the LULUCF Guidance for GHG Project Accounting (GHG Protocol, 2006). The FRESCOS Tool can also be applied for preliminary estimates of the potential of forestry project in generating voluntary carbon credits. Similarly, the FRESCOS Tool results can be used as a basis for calculating financed emissions according to the Partnership for Carbon Accounting Financials (PCAF, 2020) standard.

6. Concluding remarks

As stated at the beginning, this document follows the general principles of the IPCC (2006) tiered methodology for estimating carbon sequestration and emissions in the AFOLU sector at the national level. The IPCC Guidelines have been applied in a way that is suitable for project level carbon accounting in the FRESCOS Tool. The results of the calculations will provide the tool user an understanding of 1) the overall carbon balance of a forest asset and 2) the carbon stock development in different forest carbon pools under different forest management scenarios. The results can be used as an estimation of the current carbon sequestration and future carbon sequestration potential of a forestry project.

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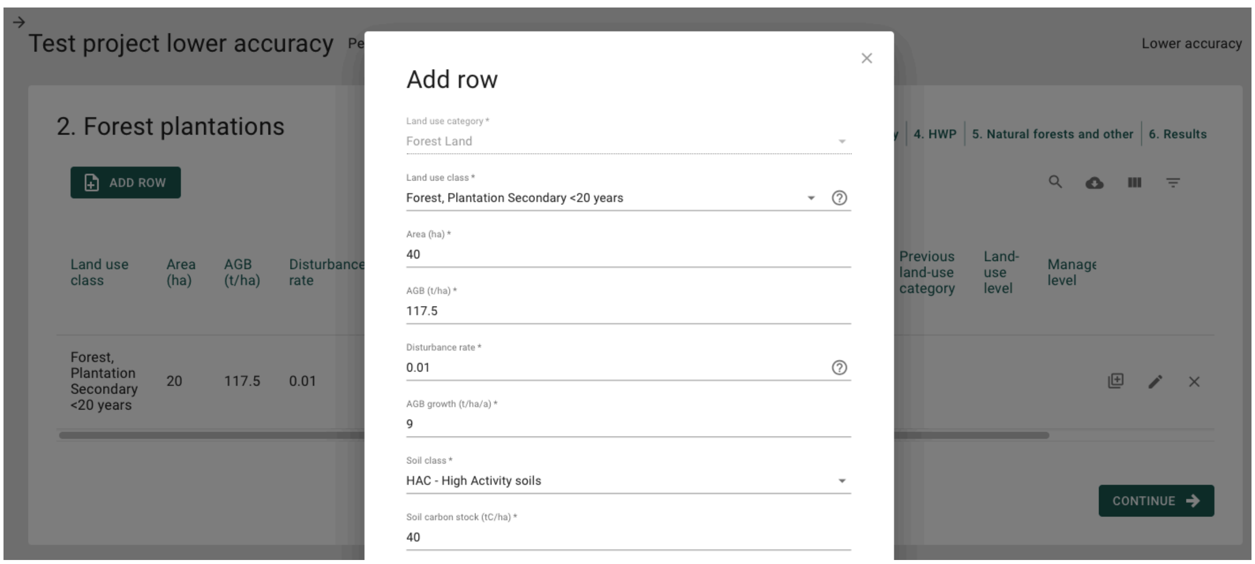
Annex 1. Illustrative examples of the FRESCOS Tool

In Annex 1. two examples are given for the use of FRESCOS tool: one at the lower and the other at the higher level of accuracies.

The lower level of accuracy

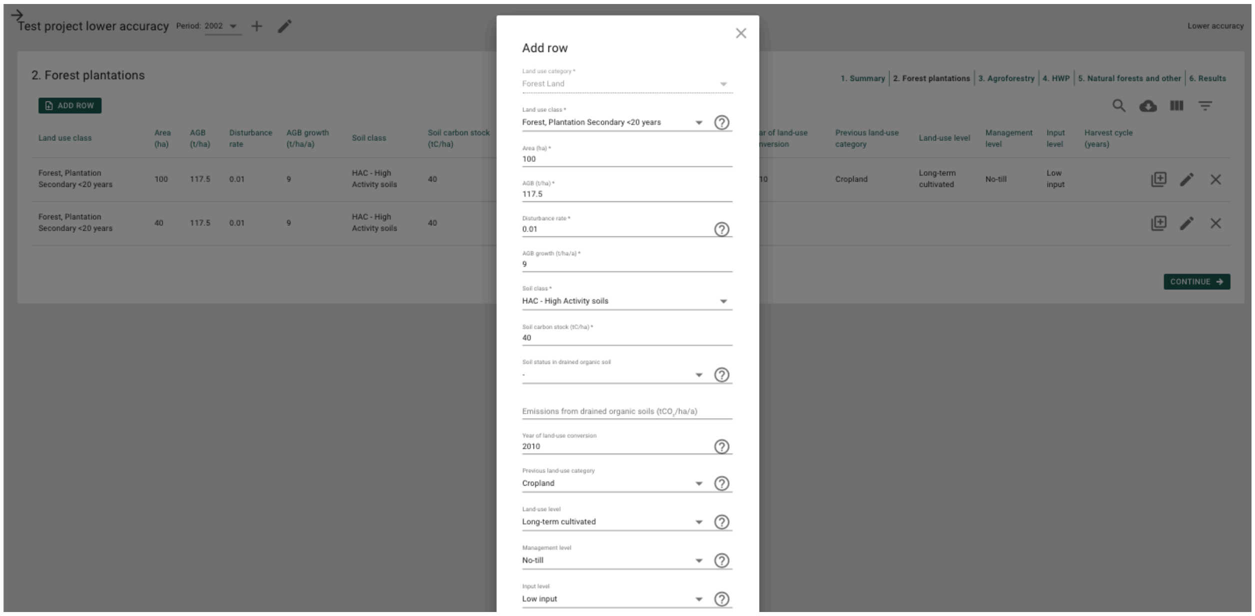
The first example is for a forestry project in Zambia with limited biomass data. For the purpose, the lower level of accuracy, and accordingly IPCC Tier 1 default values, are applied. The *Climate zone*, *Continent* and *Region* as well as the selected *level of accuracy* are reported as basic information when creating a new project (example view in Picture 4). The forest area of *40 hectares* (Picture 1) is known to consist of *Young secondary plantation <20 years*. The area is not likely to face any significant disturbances and hence a *Disturbance rate* of 0.01 is selected to capture the impact of natural tree mortality. Podzol is the main soil group in the area, which in the IPCC classification falls under *HAC-High activity clay soils* (IPCC, 2019. p.3.49-50). The area is not drained nor converted so other inputs are not needed.



Picture 1. Reporting of the inputs for the 40 hectares of remaining land at the lower level of accuracy

In addition, the forestry project includes *100 hectares* of converted land (Picture 2). Similarly to the remaining land, the converted land is nowadays considered *Young secondary plantation <20 years* with similar soil conditions. The land-use conversion took place in *2010* when the previous *Cropland* was cleared for Forest Land. Prior to Forest Land, the land had been *set aside* for some years, without land management or *Tillage*. Vegetation was assumed to be scarce creating a *Low input* for the soil carbon[13].

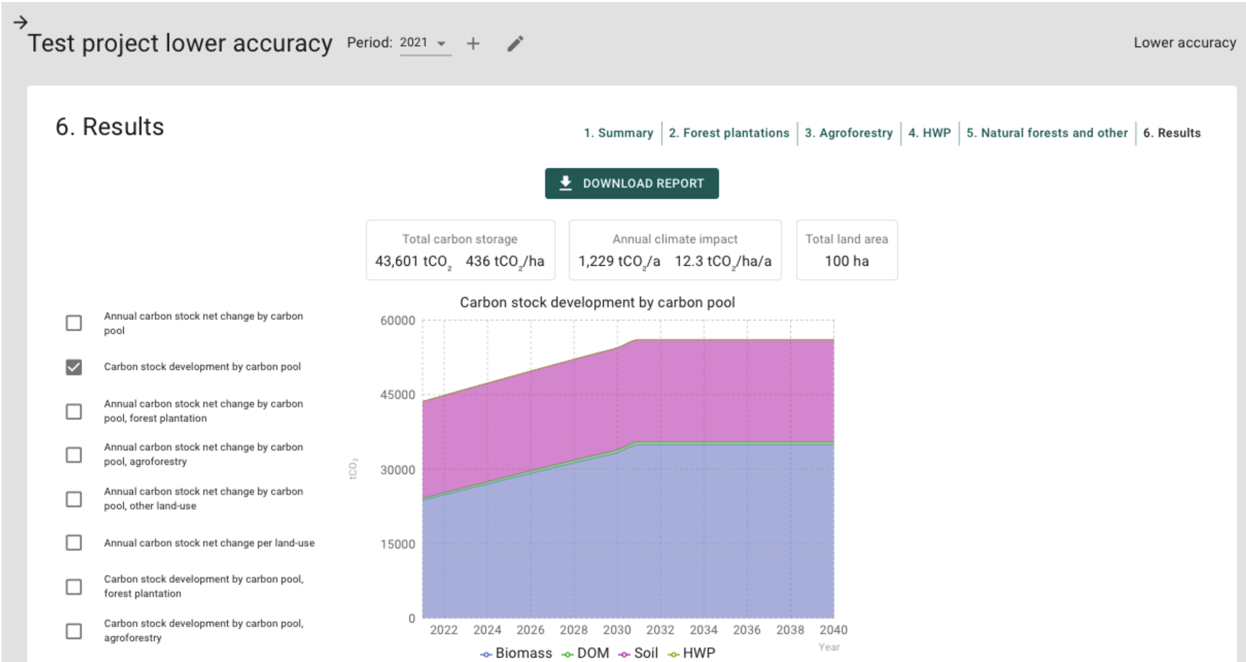
[13] The built-in soil stock change factors can be reviewed from the IPCC (2019) Table 5.5. for Cropland and Table 6.2 for Grassland (examples in Annex 9). Factor values are not provided for Forest Land. In case Forest Land is the previous land-use category, the stock change values should be developed separately to reflect local conditions and reported manually.



Picture 2. Reporting of the inputs for the 100 hectares of converted land at the lower level of accuracy

The results (Picture 3.) show the development of total carbon stocks in the project area. In the remaining land, the AGB stock is assumed to remain on the IPCC reference level for the given land-use class and continent. However, in converted land the AGB stock gradually increases over the conversion period of 20 years to the reference level, which is reached in 2030. Similarly the soil carbon stock increases from the initial level to the reference level (40 tC/ha) by 2030.

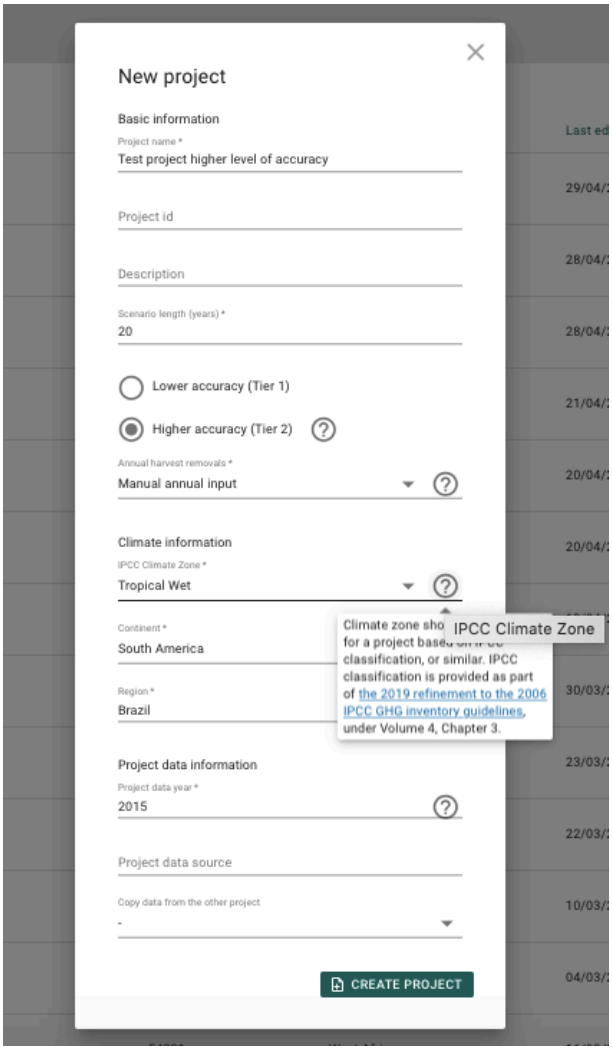
The Total carbon storage and the Annual climate impact in the Results page indicate to the *Project data year* whereas the scenario results in the figures provide more detailed figures for the 20 years onwards.



Picture 3. Carbon stock development in the area of 140 hectares including both remaining and converted lands.

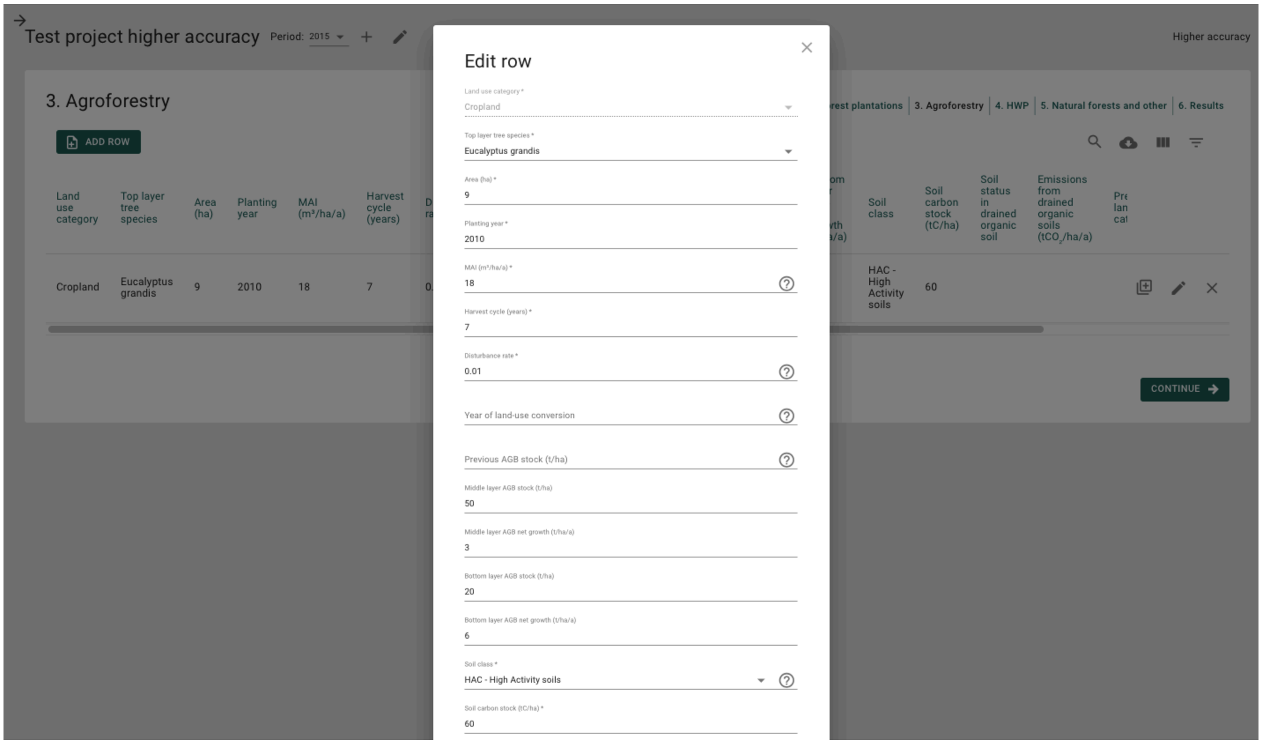
The higher level of accuracy

The following example describes an agroforestry project in Brazil. Detailed biomass data is available, and hence the higher level of accuracy is applied. However, the data is from 2015, which is reported as *Project data year* (Picture 4).



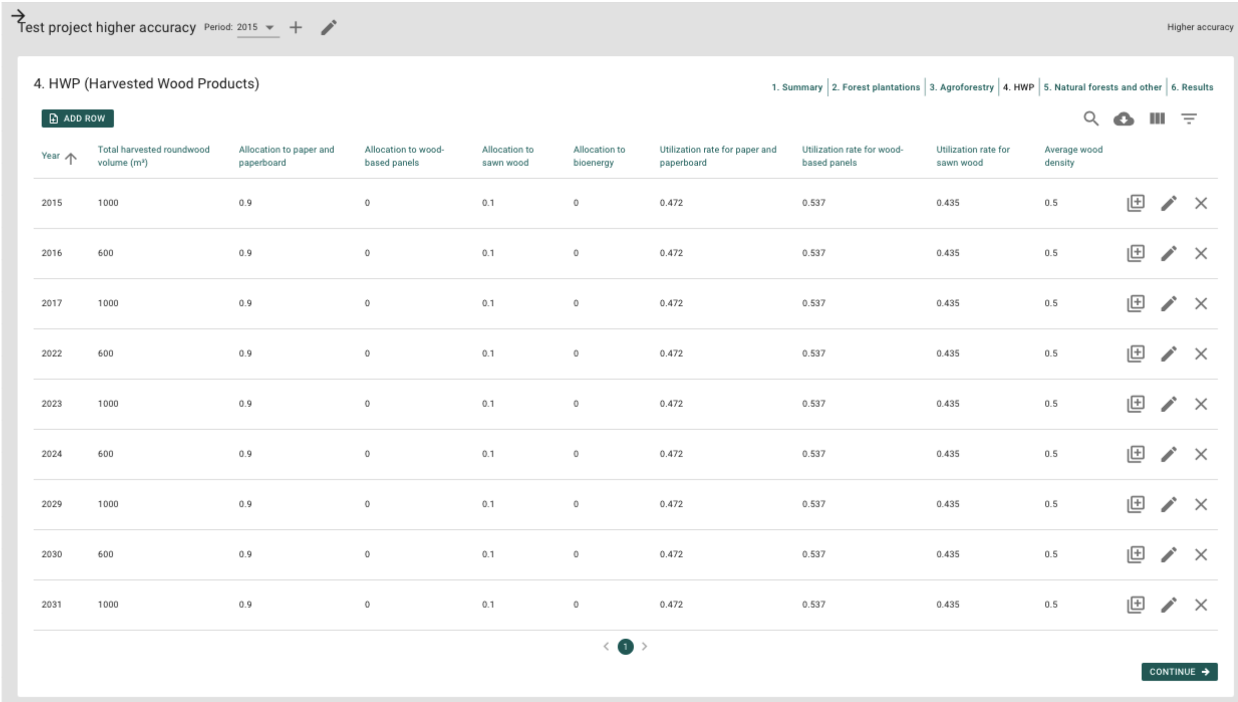
Picture 4. Inputs of basic project data

The project consists of three areas planted for *Eucalyptus grandis* in years *2008, 2009 and 2010*. The *Mean annual increment (MAI)* is known to be *18 m^3/ha* and the areas are harvested every *7 years*. The area is not likely to face any other des than natural mortality and hence a *Disturbance rate* of *0.01* is applied. In some of the areas biomass is grown in layers consisting of mixed species. In Picture 5 example inputs are shown for a mixed species area *with biomass stocks of 50 and 20 t/ha in the middle and bottom layers*. The annual *growth rates* are estimated to be *3 and 6 t/ha/a,* respectively. Luvisol is known to be the main soil group of the area, and hence according to IPCC classification (IPCC, 2019. p.3. 49-50) the soil class is set to *HAC-High Activity soils.*



Picture 5. Example inputs for a mixed species area in an agroforestry system where E. grandis is grown at the top level

The areas are harvested every *7 years*. Future harvest plan is set to follow the realized historical harvestings generating *600 or 1000 metric cubic of harvested wood* annually. *10%* of harvested wood is assumed to be used in sawn wood production, *90%* for paper and paperboard production (Picture 6). The default wood density was corrected to *0,45 t/m³* according to the given basic wood density for E. grandis in FRESCOS Tree species library. In the absence of local data, the suggested default utilization rates were used.



Test project higher accuracy Period: 2015

Higher accuracy

4. HWP (Harvested Wood Products)

1. Summary | 2. Forest plantations | 3. Agroforestry | 4. HWP | 5. Natural forests and other | 6. Results

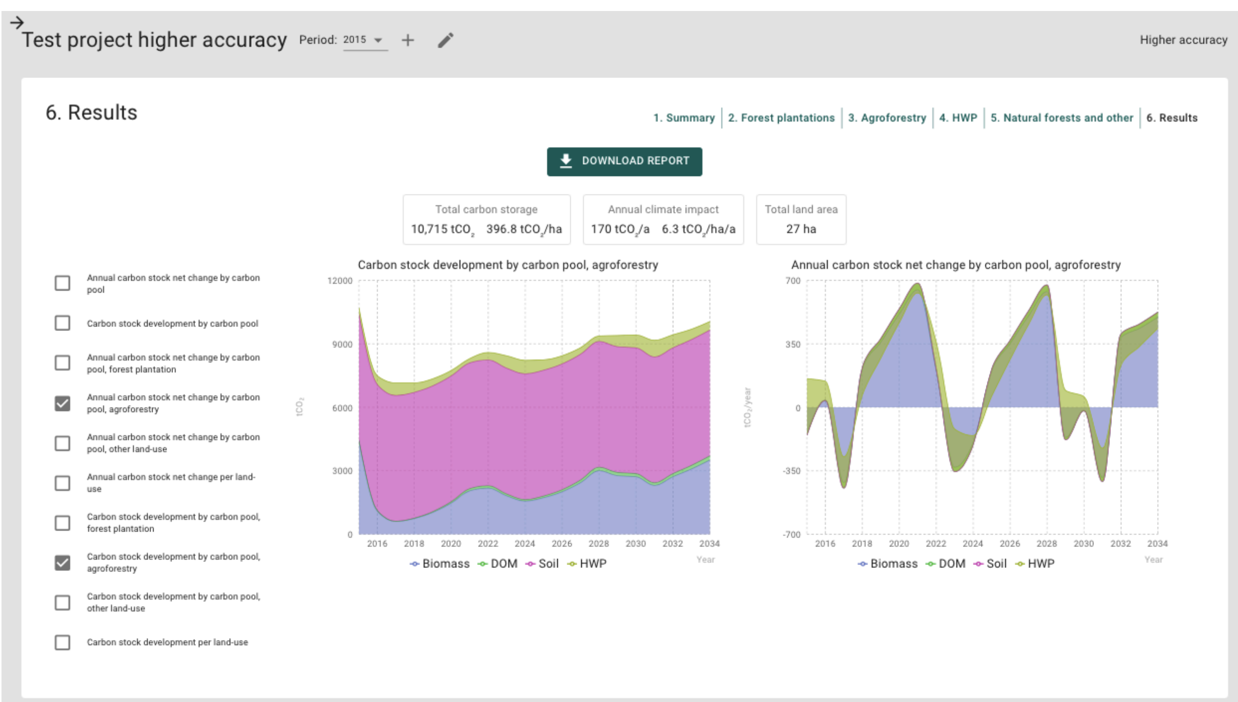
ADD ROW

Year	Total harvested roundwood volume (m³)	Allocation to paper and paperboard	Allocation to wood-based panels	Allocation to sawn wood	Allocation to bioenergy	Utilization rate for paper and paperboard	Utilization rate for wood-based panels	Utilization rate for sawn wood	Average wood density
2015	1000	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2016	600	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2017	1000	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2022	600	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2023	1000	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2024	600	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2029	1000	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2030	600	0.9	0	0.1	0	0.472	0.537	0.435	0.5
2031	1000	0.9	0	0.1	0	0.472	0.537	0.435	0.5

CONTINUE

Picture 6. Example inputs for HWP calculations for harvested E. grandis

The example of the Results (Picture 7) shows the carbon stock development as well as the development of the annual change over the years. The shape of the graph is determined by the harvests every 7 years.



Picture 7. Carbon stock development in the area of 25 hectares of remaining agroforestry land

Annex 2. IPCC default values for the AGB in agroforestry systems containing perennial species (IPCC, 2019, p. 5.8)

TABLE 5.1 (UPDATED[1])
DEFAULT COEFFICIENTS FOR ABOVE-GROUND BIOMASS AND HARVEST/MATURITY CYCLES IN AGROFORESTRY SYSTEMS CONTAINING PERENNIAL SPECIES[2]

Climate Region	Agroforestry system[3]	N	Tree density (Stems ha^{-1})	Maximum above-ground biomass carbon stock at harvest ***L_{max} (tonnes C ha^{-1})	Harvest /Maturity cycle** (yr)	Biomass accumulation rate (G)* (tonnes C ha^{-1} yr^{-1})	Mean biomass carbon loss *** (L_{mean}) (tonnes C ha^{-1} yr^{-1})
Tropical	Fallow	69	6074	22.1 ± 52%	5 ± 50%	4.42 ± 15%	11.1 ± 26%
	Hedgerow[4]	3	1481	9.4 ± 59%	20 ± 50%	0.47 ± 31%	4.7 ± 29%
	Alley cropping	90	8568	47.4 ± 52%	20 ± 50%	2.37 ± 13%	23.7 ± 26%
	Multistrata	51	929	65.0 ± 54%	20 ± 50%	3.25 ± 21%	32.5 ± 27%
	Parkland	7	152	11.8 ± 76%	20 ± 50%	0.59 ± 58%	5.9 ± 38%
	Shaded Perennial	28	4236	48.0 ± 55%	20 ± 50%	2.4 ± 24%	24.0 ± 28%
	Silvoarable	22	880	72.2 ± 60%	20 ± 50%	3.61± 33%	36.1 ± 30%
	Silvopasture	18	1609	58.2 ± 80%	20 ± 50%	2.91 ± 63%	29.1 ± 40%
Temperate	Hedgerow[4]	12	816	26.1 ± 59%	30 ± 33%	0.87 ± 49%	13.1 ± 29%
	Silvoarable	14	202	27.3 ± 62%	30 ± 33%	0.91 ± 52%	13.7 ± 31%
	Silvopasture	10	854	69.9 ± 61%	30 ± 33%	2.33 ± 52%	35.0 ± 31%

Annex 3. Example of IPCC default values for the AGB in perennial Cropland monocultures

(IPCC, 2019; p. 5.12)

TABLE 5.3 (UPDATED[1])
DEFAULT MAXIMUM AND TIME-AVERAGED MEAN ABOVE-GROUND BIOMASS AND ABOVE GROUND BIOMASS ACCUMULATION RATE FOR PERENNIAL CROPLAND MONOCULTURES (TONNES HA^{-1})

Domain	Cropping system	Maximum above-ground biomass carbon stock at harvest (L_{max}) (tonnes C ha^{-1})	Harvest /Maturity cycle (yr)	Above-ground biomass accumulation rate (G) (tonnes C ha^{-1} yr^{-1})	Mean biomass carbon stock (L_{mean}) (tonnes C ha^{-1})	References
Temperate	Olive	9.1 ± 15%	20 ± 23%	0.46 ± 27%	6.9 ± 25%	[1]
	Orchard e.g. apple	8.5 ± 19%	20 ± 42%	0.43 ± 46%	6.4 ± 25%	[1]
	Vine e.g. grape	5.5 ± 18%	20 ± 18%	0.28 ± 26%	2.8 ± 25%	[1]
	Short Rotation Coppice	12.69 ± 40%	4	3.2 ± 40%	6.35 ± 40%	[2] + adjust-ment from [3]
Tropical	Oil palm *Elaeis guineensis*	60.0 ± 41%	25	2.4 ± 41%	30.0 ± 41%	[4]
	Rubber *Hevea brasiliensis*	80.2 ± 15%	27	3.0 ± 13%	40.1 ± 15%	[5]
All	Tea *Camelia sinensis*	20.7 ± 50%	30	0.7 ± 25%	18.3 ± 25%	[6]

Annex 4. Example of IPCC default values for the AGB in Forest Land

(IPCC, 2019, p. 4.51)

TABLE 4.12 (UPDATED) (CONTINUED)
BIOMASS VALUES FROM TABLES 4.7–4.10

Domain	Ecological zone[1]	Continent	Status/ condition	Above-ground biomass in natural forests (tonnes d.m. ha^{-1})[2]	Above-ground biomass in forest plantations (tonnes d.m. ha^{-1})[3]	Above-ground net biomass growth in natural forests (tonnes d.m. ha^{-1} yr^{-1})[4]	Above-ground net biomass growth in forest plantations (tonnes d.m. ha^{-1} yr^{-1})[5]
Sub-tropical	Sub-tropical mountain systems	Africa	Primary	35.1	n.a.	n.a.	n.a.
			Secondary >20 years	35.1	30-150	0.5	10
			Secondary ≤ 20 years	35.1	10-100	2.5	10
		North and South America	Primary	74.6	n.a.	n.a.	n.a.
			Secondary >20 years	74.6	24.9-170	0.5	2-18
			Secondary ≤20 years	74.6	3.7-170	2.5	2-18
		Asia	Primary	250.2	n.a.	n.a.	n.a.
			Secondary >20 years	155.2	n.a.	0.5	1-12
			Secondary ≤20 years	155.2	8.9-103.5	2.5	1-12
Temperate	Mountain	Asia	Primary	n.a.	n.a.	n.a.	n.a.
			Secondary >20 years	170.4	n.a.	n.a.	3.0
			Secondary ≤ 20 years	n.a.	16.6-34.6	n.a.	3.0
		Europe	Primary	301.1	n.a.	n.a.	n.a.
			Secondary >20 years	214.7	n.a.	n.a.	3.0
			Secondary ≤20 years	27.8	n.a.	n.a.	3.0
		North and South America	Primary	n.a.	n.a.	n.a.	n.a.
			Secondary >20 years	185.9	29.1-89.2	4.4	9
			Secondary ≤20 years	57.9	3.0-56.0	3.1	10
	Continental	Asia	Primary	n.a.	n.a.	n.a.	n.a.
			Secondary >20 years	116	54.5-132.1	n.a.	4.0
			Secondary ≤ 20 years	90.9	18-66.7	n.a.	4.0
		Europe	Primary	332.4	n.a.	n.a.	n.a.
			Secondary >20 years	162	n.a.	n.a.	4.0
			Secondary ≤20 years	51.6	n.a.	n.a.	4.0

Annex 5. IPCC default reference condition soil organic carbon stocks for mineral soils

(IPCC, 2019, p. 2.35)

TABLE 2.3 (UPDATED)
DEFAULT REFERENCE CONDITION SOIL ORGANIC CARBON STOCKS (SOC_{REF}) FOR MINERAL SOILS (TONNES C HA^{-1} IN 0-30 CM DEPTH) [1, 2]

IPCC Climate Zone [5]	IPCC soil class [6]		
	High activity clay soils (HAC) [7]	**Low activity clay soils (LAC) [8]**	**Sandy soils (SAN) [9]**
Polar Moist/Dry (Px - undiff)[13]	59 ± 41% (24)	NA	27 ± 67% (18)
Boreal Moist/Dry (Bx - undiff)[13]	63 ± 18% (35)	NA	10 ± 90% [4]
Cool temperate dry (C2)	43 ± 8% (177)	33 ± 90% [3]	13 ± 33% (10)
Cool temperate moist (C1)	81 ± 5% (334)	76 ± 51% (6)	51 ± 13% (126)
Warm temperate dry (W2)	24 ± 5% (781)	19 ± 16% (41)	10 ± 5% (338)
Warm temperate moist (W1)	64 ± 5% (489)	55 ± 8% (183)	36 ± 23% (39)
Tropical dry (T4)	21 ± 5% (554)	19 ± 10% (135)	9 ± 9% (164)
Tropical moist (T3)	40 ± 7% (226)	38 ± 5% (326)	27 ± 12% (76)
Tropical wet (T2)	60 ± 8% (137)	52 ± 6% (271)	46 ± 20% (43)
Tropical montane (T1)	51 ± 10% (114)	44 ± 11% (84)	52 ± 34% (11)
	Spodic soils (POD) [10]	**Volcanic soils (VOL) [11]**	**Wetland soils (WET) [12]**
Polar Moist/Dry (Px - undiff)[13]	NO	NA	NA
Boreal Moist/Dry (Bx - undiff)[13]	117 ± 90% [3]	20 ± 90% [4]	116 ± 65% (6)
Cool temperate dry (C2)	NO	20 ± 90% [4]	87 ± 90% [3]
Cool temperate moist (C1)	128 ± 14% (45)	136 ± 14% (28)	128 ± 13% (42)
Warm temperate dry (W2)	NO	84 ± 65% (10)	74 ± 17% (49)
Warm temperate moist (W1)	143 ± 30% (9)	138 ± 12% (42)	135 ± 28% (28)
Tropical dry (T4)	NA	50 ± 90% [4]	22 ± 17% (32)
Tropical moist (T3)	NA	70 ± 90% [4]	68 ± 17% (55)
Tropical wet (T2)	NA	77 ± 27% (14)	49 ± 19% (33)
Tropical montane (T1)	NA	96 ± 31% (10)	82 ± 50% (12)

Annex 6. Example of emission/removal factors for drained organic soils

(IPCC, 2013; p. 2.9)

TABLE 2.1
TIER 1 CO_2 EMISSION/REMOVAL FACTORS FOR DRAINED ORGANIC SOILS IN ALL LAND-USE CATEGORIES*

Land-use category		Climate / vegetation zone	Emission Factor[a] (tonnes CO_2-C ha^{-1} yr^{-1})	95% Confidence Interval[b]		No. of sites	Citations/comments
Forest Land, drained, including shrubland and drained land that may not classify as forest[c]	Nutrient-poor	Boreal	0.37	-0.11	0.84	63	Lohila *et al.*, 2011; Minkkinen & Laine, 1998; Minkkinen *et al.*, 1999; Ojanen *et al.*, 2010, 2013; Simola *et al.*, 2012
Forest Land, drained[d]	Nutrient-poor	Boreal	0.25	-0.23	073	59	Lohila *et al.*, 2011; Minkkinen & Laine, 1998; Minkkinen *et al.*, 1999; Ojanen *et al.*, 2010, 2013; Simola *et al.*, 2012
	Nutrient-rich	Boreal	0.93	0.54	1.3	62	Laurila *et al.*, 2007 ; Lohila *et al.*, 2007; Minkkinen & Laine, 1998; Minkkinen *et al.*, 1999, 2007b; Ojanen *et al.*, 2010, 2013; Simola *et al.*, 2012
Forest Land, drained		Temperate	2.6	2.0	3.3	8	Glenn *et al.*, 1993; Minkkinen *et al.*, 2007b; Von Arnold *et al.*, 2005a,b, Yamulki *et al.*, 2013
Forest Land and cleared Forest Land (shrubland[e]), drained		Tropical	5.3	-0.7	9.5	21	Ali *et al.*, 2006; Brady, 1997; Chimner & Ewel, 2005; Comeau *et al.*,2013; Dariah *et al.*, 2013; Darung *et al.*, 2005; Furukawa *et al.*, 2005; Hadi *et al.*, 2005; Harisson *et al.*, 2007; Hergoualc'h & Verchot, 2011; Hertel *et al.*, 2009; Hirano *et al.*, 2009, 2012; Inubushi *et al.*, 2003; Ishida *et al.*, 2001; Jauhiainen *et al.*, 2008, 2012a; Melling *et al.*, 2005a, 2007a; Rahaoje *et al.*, 2000; Shimamura & Momose, 2005; Sulistiyanto, 2004; Sundari *et al.*, 2012
Plantations, drained, unknown or long rotations[f]		Tropical	15	10	21	n/a.	Average of emission factors for *Acacia* and oil palm
Plantations, drained, short rotations, e.g. *Acacia*[f, g],		Tropical	20	16	24	13	Basuki *et al.*, 2012; Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012a; Nouvellon *et al.*, 2012; Warren *et al.*, 2012
Plantations, drained,.oil palm[f]		Tropical	11	5.6	17	10	Comeau *et al.*, 2013; Dariah *et al.*, 2013; DID and LAWOO, 1996; Henson and Dolmat, 2003; Hooijer et al., 2012; Couwenberg, and Hooijer 2013; Lamade and Bouillet, 2005; Marwanto and Agus,

Annex 7. CDM default factors for litter and dead wood

DF for litter (CDM, AR-TOOL12, p. 19)

Biome	Elevation	Precipitation	DF_{LI}
Tropical	<2000m	<1000 mm yr^{-1}	4%
Tropical	<2000m	1000-1600 mm yr^{-1}	1%
Tropical	<2000m	>1600 mm yr^{-1}	1%
Tropical	>2000m	All	1%
Temperate/ boreal	All	All	4%

DF for dead wood (AR-TOOL12, p. 18)

Biome	Elevation	Precipitation	DF_{DW}
Tropical	<2000m	<1000 mm yr^{-1}	2%
Tropical	<2000m	1000-1600 mm yr^{-1}	1%
Tropical	<2000m	>1600 mm yr^{-1}	6%
Tropical	>2000m	All	7%
Temperate/ boreal	All	All	8%

Annex 8. Tier 1 default half-lives of HWP commodity classes

(IPCC, 2019; p. 12.28)

TABLE 12.3 TIER 1 DEFAULT HALF-LIVES[16] OF HWP COMMODITY CLASSES	
HWP commodity classes[17]	**Default half-life (years)**
Paper and paperboard	2
Wood-based panels	25
Sawn wood	35
Source: IPCC 2014	

Annex 9. Soil carbon stock change factors for Cropland and Grassland

Example of IPCC soil stock change factor values for Cropland (IPCC, 2019; p. 5.27-28)

TABLE 5.5 (UPDATED)
RELATIVE CARBON STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temperature regime	Moisture regime[1]	IPCC defaults	Error[2,3]	Description
Land use[5] (F_{LU})	Long-term cultivated	Cool Temperate/ Boreal	Dry	0.77	±14%	Represents area that has been converted from native conditions and continuously managed for predominantly annual crops over 50 yrs. Land-use factor has been estimated under a baseline condition of full tillage and nominal ('medium") carbon input levels. Input and tillage factors are also applied to estimate carbon stock changes, which includes changes from full tillage and medium input.
			Moist	0.70	±12%	
		Warm Temperate	Dry	0.76	±12%	
			Moist	0.69	±16%	
		Tropical	Dry	0.92	±13%	
			Moist/Wet	0.83	±11%	
Land use[6] (F_{LU})	Paddy rice	All	Dry and Moist/Wet	1.35	±4%	Long-term (> 20 year) annual cropping of wetlands (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used.
Land use[5] (F_{LU})	Perennial/ Tree Crop	Temperate/ Boreal	Dry and Moist	0.72	±22%	Long-term perennial tree crops such as fruit and nut trees, coffee and cacao.
		Tropical	Dry and Moist/Wet	1.01	±25%	
Land use (F_{LU})	Set aside (< 20 yrs)	Temperate/ Boreal and Tropical	Dry	0.93	±11%	Represents temporary set aside of annually cropland (e.g., conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
			Moist/Wet	0.82	±17%	
		Tropical montane[44]	n/a	0.88	±50%	
Tillage (F_{MG})	Full	All	Dry and Moist/Wet	1.00	n/a	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.

The IPCC soil stock change factor values for Grassland (IPCC, 2019; p. 6.6)

Table 6.2 (Updated) Relative stock change factors for grassland management					
Factor	**Level**	**Climate regime**	**IPCC default**	**Error [1,2]**	**Definition**
Land use (F_{LU})	All	All	1.0	NA	All native and/or permanent grassland in a nominal condition is assigned a land-use factor of 1.
Management (F_{MG})	Nominally managed (non – degraded)	All	1.0	NA	Represents low or medium intensity grazing regimes, in addition to periodic cutting and removal of above-ground vegetation, without significant management improvements.
Management (F_{MG})	High Intensity Grazing[3]	All	0.90	±8%	Represents high intensity grazing systems (or cutting and removal of vegetation) with shifts in vegetation composition and possibly productivity but is not severely degraded[4].
Management (F_{MG})	Severely degraded	All	0.7	±40%	Implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.
Management (F_{MG})	Improved grassland	Temperate/ Boreal	1.14	±11%	Represents grassland which is sustainably managed with light to moderate grazing pressure (or cutting and removal of vegetation) and that receive at least one improvement (e.g., fertilization, species improvement, irrigation).
		Tropical	1.17	±9%	
		Tropical Montane[5]	1.16	±40%	
Input (applied only to improved grassland) (F_I)	Medium	All	1.0	NA	Applies to improved grassland where no additional management inputs have been used.
Input (applied only to improved grassland) (F_I)	High	All	1.11	±7%	Applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that required to be classified as improved grassland).