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A European reporting and accounting framework for the LULUCF Sector

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III. Abbreviations

LULUCF	Land Use Land-Use Change and Forestry
IPCC	Intergovernmental Panel on Climate Change
EU	European Union
AGB	Above-ground Biomass
BGB	Below-ground Biomass
NFI	National Forest Inventory
DOM	Dead Organic Matter
HWP	Harvested Wood Products
FAO	Food and Agricultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
CRF	Common Reporting Format
EFDM	European Forestry Dynamics Model
ICPF	International Co-operative Programme on Forests
NIR	National Inventory Report
GHG	Greenhouse Gas
IAM	Integrated Assessment Model
EEA	European Environment Agency
NUTS	Nomenclature of Territorial Units for Statistics
SOC	Soil Organic Carbon
GIS	Geographic Information System
EEA	European Environmental Agency

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1. Summary

The framework aims to harmonise LULUCF reporting across EU member states, focusing primarily on forest land reporting, and addressing current inconsistencies in methodological approaches. It converts estimates from multiple data sources, including the PathFinder project's high-resolution remote sensing and field observations, into standardised reporting formats that align with IPCC guidelines and EU requirements.

The framework uses two main approaches: pixel counting of remote sensing-based maps, and a model-assisted approach for statistical calibration with NFI data. Soil and dead organic matter estimates are derived from the Yasso model using ICP Forest Level II plot data to estimate litterfall, while harvested wood products calculations follow default IPCC methods using FAO statistics. Future forecasting to 2100 is incorporated using the European Forestry Dynamics Model (EFDM) combined with CLUMondo scenarios, accounting for management activities, natural disturbances, and land-use changes. These projections follow the same conversion methods to ensure consistency with current reporting.

The framework employs both Tier 1 methods (using default emission factors) and Tier 3 methods (utilising NFI measurements and high-resolution modelling). The analysis includes detailed comparisons of land representation approaches, methodological tiers, and key definitions between national inventories and the framework. While the methodology has been established, quantitative comparisons between national GHG inventories and the PathFinder approach are pending completion of data processing to determine impacts on reported emissions at EU and national levels.

2. Introduction

The Land Use, Land-Use Change and Forestry (LULUCF) sector plays a crucial role in climate change mitigation efforts. However, the difference in reporting methodologies across EU member states presents a significant challenge for comparing estimates within the EU and accurately assessing progress towards climate goals (Giacomo Grassi, 2010). PathFinder Task 4.2 - ‘To develop an EU reporting & accounting framework for the LULUCF sector’ aims to address this issue by developing a harmonised reporting and accounting framework for the LULUCF sector that aligns with IPCC guidelines while meeting specific EU policy requirements.

This task is integral to the broader objectives of the PathFinder project, utilising inputs from other work packages to create a common approach to forest monitoring and climate action. This builds upon the forest monitoring system currently in development which integrates high-resolution remote sensing data with extensive field observations to produce wall-to-wall aboveground-biomass maps and likewise uses the soil modelling efforts to produce emission estimates for soil and dead organic matter. Furthermore, carbon stock changes will also be produced for every five-year period up to 2100 derived from forestry dynamic models and stakeholder workshops ensuring that the framework is robust and adaptable to future forest scenarios and management pathways.

The necessity for such a harmonised framework stems from the current differences in methodological approaches among EU member states. These differences, which range from varied forest definitions to mixed carbon estimating methods, can lead to inconsistencies in reported emissions and removals. By standardising these methodologies, Task 4.2 seeks to enhance the comparability of LULUCF reporting across the EU while meeting the updated EU LULUCF regulation.

The second part of this deliverable also looks to assess the methodological differences between national inventories and the harmonised reporting framework. This includes the definitions employed, land use approaches, IPCC tiers and emission factors. Further quantitative analysis will also be carried out to understand the reporting impacts at the EU and country level when data becomes available.

While the LULUCF sector is wide-ranging in its reporting requirements, including various land types such as croplands, settlements and grassland, the scope of this framework mainly sits within the forest land category and land converted to and from forest land. Additionally, the full LULUCF reporting also includes other land-based emissions such as biomass burning, non-CO2 emissions such as nitrous oxide from nitrogen inputs to soil, drained organic soils, mineralisation, immobilization, leaching, runoff and deposition. These emissions, while also taking place within forest lands, are considered out of scope and will not be estimated and reported as part of this task.

3. Methodology

The following section will detail the method for converting the estimates from the model outputs and the necessary conversions required for reporting guidelines. Methods and further details on consistent capture of plot-level data, model design and mapping are captured in earlier work packages.

3.1 Data Sources

As the estimates will come from various sources, the first part of the section will list the required inputs, from where they are sourced and what approach is used to generate the data.

Table 1: input data and their sources used to generate forest land C stock changes

Inputs for Forest Land	**Source**	**Approach**
• Living biomass (AGB and BGB) stock changes • Forest Area	High-Resolution Pan European Forest Structure Maps (Miettinen, Adame, et al., 2024)	Remote Sensing + NFI plots, biomass coversion factors for BGB, resulting in Biomass Maps, Copernicus HRL 2018 for forest area (implicitly included in Biomass Maps), Pixel counting (synthetic) estimates
• AGB Stock Changes • Forest Area	nFiesta Estimates	Biomass Maps + NFI plots, direct and model assisted estimates
• Soil & DOM Stock Changes • Soil Area	Yasso Model Estimates	ICP Forest Level II Soil Survey Data
• Harvested Wood Products	Food & Agricultural Organisation (FAO)	National Data Estimates
• Forecasted Living Biomass Stock Changes • Forecasted Soil Biomass Stock Changes • Forecasted Wood Harvests • Forecasted Species Type Map	European Forestry Dynamics Model (EFDM)	CLUMondo + Biomass Maps

3.2 Living biomass

Above-ground living biomass (AGB) estimates will be derived using two approaches in PathFinder. The first approach combines Sentinel 2 mosaic, Copernicus layers and NFI data to produce pixel-based maps (resolution 10 x10 m^2) for AGB maps, from which the gains and losses can be calculated. This approach, while timely and provides full area coverage, tends to result in biased estimates and will require further field-based data at a regional level to calibrate the maps for further accuracy (Miettinen, Adame, et al., 2024).

The second approach combines high-resolution biomass maps (approach described above) with National Forest Inventory data through the nFIESTA (new Forest Inventory ESTimation and Analysis) system. This statistical estimation tool improves estimates for small regions to pan-EU scale by incorporating NFI plot data with remotely sensed data in multiphase designs using model-assisted or model-based estimators. This approach generally results in more robust estimates than pixel-based methods alone, particularly at larger spatial scales, as it leverages the statistical properties of probability sampling from NFIs while gaining precision from the auxiliary remote sensing data (Miettinen, Adolt, et al., 2024).

Biomass conversion factors will be used to derive BGB from AGB.

3.2.1 Approach 1- Pixel counting Model Based

Input Data

AGB stock changes will be obtained from the 10x10 m2 Pan-European maps from deliverable 2.1. The above-ground biomass losses will be calculated by overlaying the Pan-European map with the Global Forest Change loss data. This combined dataset will highlight each forest pixel with the area of forest loss to give the amount of forest loss assuming that a high proportion of biomass under the 'tree cover loss' pixel is lost.

The biomass gains will be received directly as one of the final products from the mapping outputs. Hence, no further mapping overlays are required. Forest area will also be derived using the pixel values and converting them to an area format using GIS software.

Conversions

Default emission factors from the 2019 IPCC Good Guidance will be used to calculate the belowground living biomass (BGB) estimates from aboveground living biomass. These values are detailed in the following table 2.

Table 2- Ratio (R) of below ground biomass to above ground biomass - (IPCC, 2019) Table 4.4

Domain	Ecological Zone	Continent	Origin	Aboveground Biomass (tonnes per hectare)	R
Temperate	Oceanic	Europe	Natural (Other Broadleaf)	≤ 125	0.213
Temperate	Oceanic	Europe	Natural (Other Broadleaf)	>125	0.313
Temperate	Oceanic	Europe	Planted (Conifer)	≤ 125	0.634
Temperate	Oceanic	Europe	Planted (Conifer)	>125	0.294

Temperate	Continental	Europe	Planted (Conifer)	≤ 125	0.340
Boreal	Coniferous, tundra woodland, mountain systems	-	-	> 75	0.240
Boreal	Coniferous, tundra woodland, mountain systems	-	-	≤ 75	0.390

The FAO climatic region shapefile map will be used to classify the regions according to the table above while the Deciduous-Conifer proportion map included as part of the input data allows more detailed emission factors to be used for calculating the below-ground biomass estimates. Combining both the AGB and BGB values, deducing the carbon content (half of the biomass) and multiplying by 44/12 then gives the total carbon dioxide emission value that can be used for reporting.

3.2.2 Approach 2- NFI Model Assisted

Input Data

Outputs from the model assisted approach utilizing NFI data will be used for biomass gains and losses at the national level (NUTS 1) including uncertainties.

Conversions

The emission factors that will be used to estimate the carbon dioxide emissions will be the same default factors used in approach one. This conversion method will then allow a comparison between approaches one and two to assess the differences in methods and uncertainties.

3.3 Mineral Soil & DOM

Input Data

The mineral soil and DOM estimates are taken directly from output data that comes from the Yasso soil model. This model is already in use by countries such as Finland, Austria, Norway and Switzerland to determine their soil, deadwood and litter estimates.

The Yasso model, as part of this framework, uses ICP Forest Level II plots that provide harmonised data on various soil carbon inputs including foliar and non-foliar litterfall, fine roots and coarse belowground roots. Further information on the preprocessing and analysis using this model can be found at https://pathfinder-heu.eu/wp-content/uploads/2024/09/PathFinder_D3.3.pdf.

Estimates from the soil carbon arrive as a single output and are not separated between the dead organic matter and soil carbon pools. Countries that currently use the Yasso model for the national inventories locate this output under the mineral soil carbon pool and do not separate them between deadwood, litter and soil, hence, the same methodology is applied here.

The Yasso modelling work does not consider waterlogged or peat lands as these are not part of its input data. Therefore, organic soil is assumed to be in equilibrium (zero change). We refer to the HorizonEurope project Holisoils for methodologies on organic soils. Additionally, Yasso does not include coarse aboveground deadwood (≥ ca. 2 cm diameter) as part of the input data due to ICPF

plots being located primarily in managed forests which meant this feature had limited input. Discrepancies between the reporting framework and national inventories in the soil and deadwood pool can assume this as a factor.

Conversions

The high-resolution soil maps showing soil biomass gains and losses will be aggregated (pixel counting) to estimates at a country scale using NUTS 1 regions. These biomass estimates will then be converted to carbon dioxide emissions using the carbon dioxide mass ratio.

3.4 Harvested Wood Products (HWP)

Input Data

Wood production outputs are taken directly from the Food and Agricultural Organisation statistics database. National inventory compilers retrieve this data from FAO datasets that contain production, import and export data on sawn wood, wood panels, paper & paperboard, industrial roundwood and wood pulp.

The IPCC produces a worksheet that automatically populates the latest relevant FAO data for calculating the emission data. This worksheet can then be used in conjunction with the IPCC inventory software to convert production data into carbon stock changes and emissions/gains (see conversion section below for further information). Both the software and spreadsheet can be found on the IPCC website(IPCC, n.d.)

Conversions

The HWP-reported values will be calculated directly using the IPCC Inventory Software v.2.93. This software automatically retrieves the latest FAO wood production, import and export data, implements the default half-life and emission factors and then finally calculates the total stock change and emissions/gains using the equations in the 2006 IPCC Good Guidance.

The EU LULUCF Legislation states that member states should use the production approach for accounting HWP meaning that all wood produced domestically shall be accounted for, including wood products that have afterwards been exported. The legislation also states that first order decay method should be used which is a type of flux method for calculating carbon stock change (On the Inclusion of Greenhouse Gas Emissions and Removals from Land Use, Land Use Change and Forestry in the 2030 Climate and Energy Framework, and Amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU, 2018).

The CRF tables group products either under ‘solid wood’ or paper and paperboard’. As default values are used for both domestic and export consumption, there is no requirement or need to differentiate between emissions for domestic or export HWP.

Tier 1 default emission factors and half-life values were used to generate carbon emissions for HWP subcategories and are listed in Table 3 and 4.

Table 3 – Half Live Values and Decay Rate – IPCC 2006 Good Guidance

Product	**Half-Life/ Years**	**Decay Rate/per year**
Sawn Wood, Other Industrial Roundwood	35	0.02
Wood Panels	25	0.028
Paper and paperboard	2	0.347

Table 4- Conversion Factors – IPCC 2006 Good Guidance

Product	**Conversion Factor/ t C/m3**
Sawn Wood, Other Industrial Roundwood	0.229
Wood Panels	0.269
Paper and paperboard	0.386

Estimates of annual change in the two product pools require data on total product production, industrial roundwood production, imports and exports from the current year back to 1900. FAO data are used back to 1961 (for countries with available data) and data back to 1900 is estimated using predetermined regional rate of change in industrial roundwood production. This rate of change value is given as a constant for all world regions in table 12.3 in the IPCC Good Guidance, which is 0.0151 for Europe (IPCC, 2003).

3.5 Forecasting Estimates

The PathFinder project implements an integrated modelling framework to forecast forest carbon stocks and fluxes to 2100. At its core, the framework combines the CLUMondo land system model, which forecasts forest area developments based on multiple demands including timber production, biodiversity and carbon storage, with the European Forestry Dynamics Model (EFDM), a matrix-based simulation tool operating at 5-year intervals. The EFDM utilises transition probabilities derived from National Forest Inventory data and incorporates the PREBAS forest ecosystem model to account for climate-sensitive growth dynamics. Natural disturbances including wind, fire, and insect outbreaks are explicitly modelled using specialised risk assessment tools (e.g., ForestGALES, Fire Weather Index) and integrated as modifications to forest state transition probabilities.

A climate emulator assesses local biophysical impacts, creating a feedback loop that allows forest development to respond dynamically to changing climatic conditions. This integrated approach produces spatially explicit projections at 1km² resolution as an input to this framework. The maps will then be converted in task 4.2 using the processes described above to ensure consistency with current reporting frameworks.

The integrated system enables evaluation of different policy pathways while maintaining methodological coherence with national greenhouse gas inventories, allowing for robust analysis of long-term forest carbon dynamics under varying management scenarios and environmental conditions.

3.6 Reporting

The forest land category emission data will be converted by running a series of scripts that takes in the input data from the models, runs the calculations and conversions defined in the methodology and outputs the data in a tabular format. This ensures consistency which reduces errors from performing many calculations. The tabular format also ensures a straightforward means of data entry to Common Reporting Tables. The reporting format will follow the Common Reporting Tables (CRT) developed by the UNFCCC, thus ensuring a standard reporting overview and consistency with previous year inventories(UNFCCC, 2021).

4. Analysis

As part of the deliverable, a comparison between the national inventory reports and the proposed reporting framework was conducted. This includes how the forest land is represented, what level of accuracy, or tier, is used to calculate estimates and where different definitions are used.

4.1 Comparison between PathFinder methodology and National Inventory Methodologies

4.1.1 Land Representation

Land representation refers to the way information on annual areas of land-use and land-use change are estimated. The IPCC defines three "approaches" (distinct from "tiers") for land representation methodologies. Indeed, these do not reflect hierarchical tiers with increasing accuracy but rather reflect data collection methods and attributes (IPCC, 2006)

- Approach 1: simple statistics on total land use areas per year, no information on conversions
- Approach 2: statistics on land-use change matrix, with information on conversions
- Approach 3: spatially explicit info of land-use and land-use change: conversions are geo-tracked

Overall, most countries in the EU use NFI data to obtain land use change data, although the design of the NFI differs from country to country. Parameters such as frequency, whether the sampled plots are permanent or temporary or if remote sensing data is incorporated. This means that some countries can be classified as using approach 2 methods and others using approach 3.

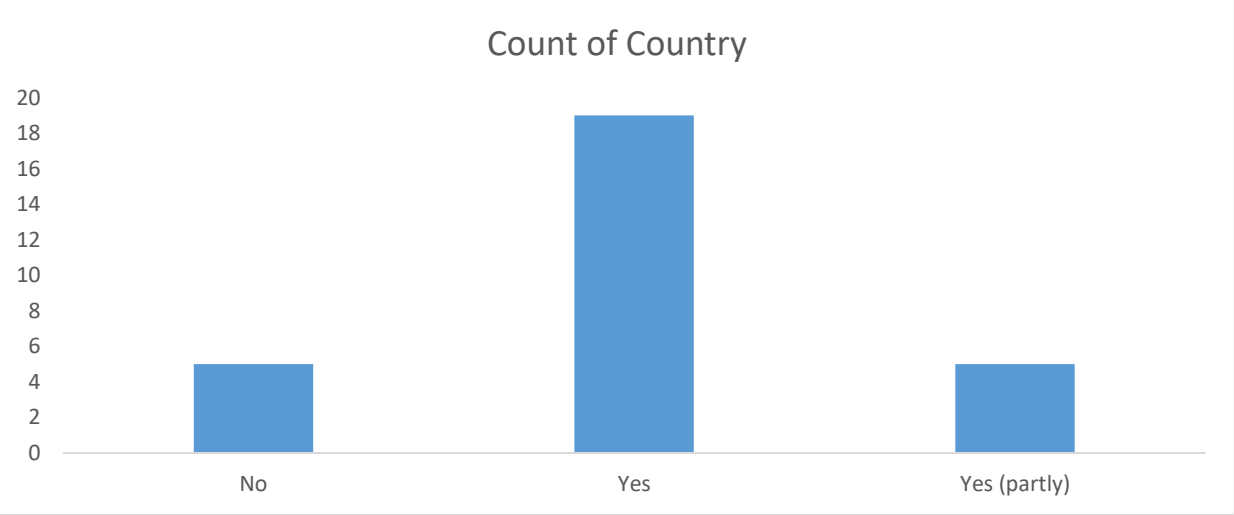

Figure 1- Count of EU countries using permanent NFI plots (Including Norway & Iceland) (Brook et al., 2023)

Although mapping approaches (as part of approach 3) do not necessarily mean higher accuracy (due to poor quality underlying data and algorithm classification errors), the higher approach offers key advantages such as:

- Timely information to give preliminary indications for implementation of policies on the field and the ability to estimate their impacts.
- Monitoring of priority areas to facilitate development of better management practices
- Improved synergies and opportunities to consolidate reporting with other relevant policy areas by being able to overlap datasets (while aware of differences in spatial and temporal resolutions). (EEA, 2024)

The land representation used in the reporting framework can be classified as approach 3 for forest land data given that the maps produced are spatially explicit and can be tracked over time, although no estimates are given for land conversion categories for the NFI model assisted approach.

4.1.2 Method Accuracy

The IPCC Guidelines implement a three-tiered method for LULUCF reporting. In general, the higher the tier the more accurate the estimate for the specific carbon pool, however, this usually means more complexity and resources involved which is not possible for all countries. As part of the NIR, countries should explicitly state which tier they are using to calculate their estimates.

Tier 1: the simplest method usually involves default parameter values (emission and stock change factors) given by the IPCC guidelines or EU Regulation for use in stock change formulas. Activity data here is usually country-specific, however, this can also be sourced from global datasets (land cover maps etc)

Tier 2: This is the same methodology and formulas used in tier 1; however, the emission and stock change factors are based on country, region or land use specific data. This is usually arrived at through analysing inventory data or specific measurements taken from the carbon pool/land.

Tier 3: This method is most complex and usual involves modelling and/or inventory measurement systems at a high resolution and repeated measurements (NFIs, Soil inventories). Several pieces of monitoring can be involved at this level which include the use of remote sensing data tracked at regular close intervals allowing tracking over time given rise to interannual variability. Given the variety of models/ measurement techniques that can be applied at this tier, documentation and evidence of verification and validation should be included in the NIRs.

(IPCC, 2006)

Given that this task objective encompasses harmonising the estimates from PathFinder models and measurements, the purpose here is to enhance comparability between the EU member states at the sacrifice of accuracy when employing using more specific modelling parameters and measurement techniques. In this way, the PathFinder methodology can be classed as using a mixture of tier 1 methods (using default emission factors) as well as tier 3 methods (NFI repeated measurements and modelling at high resolutions) for different carbon pools as per the methods described in the methodology section.

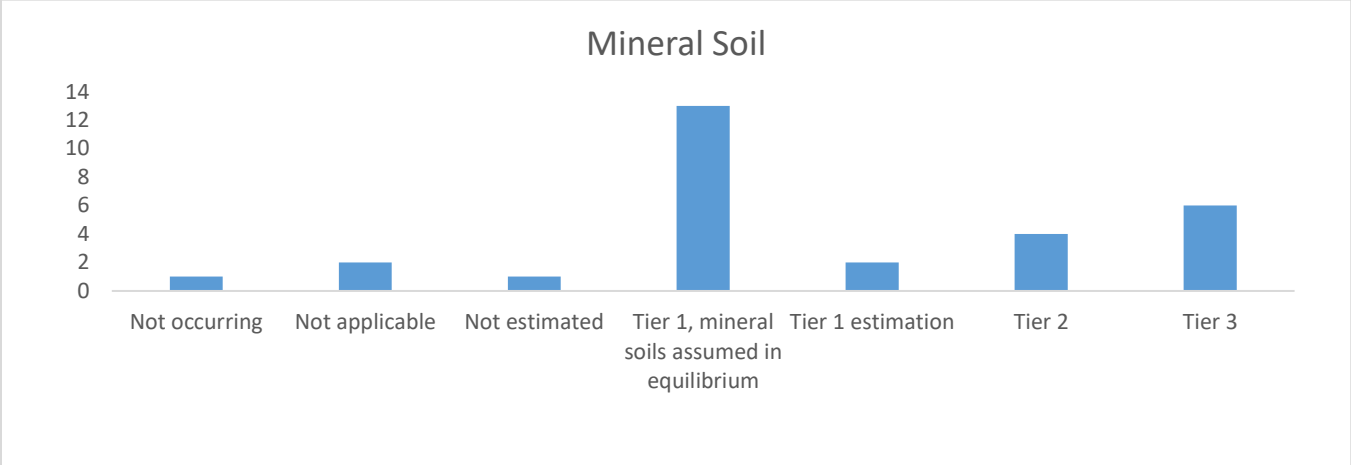

Figure 2- Mineral Soil National Tiers For EU Countries (Including Norway) – (Brook et al., 2023)

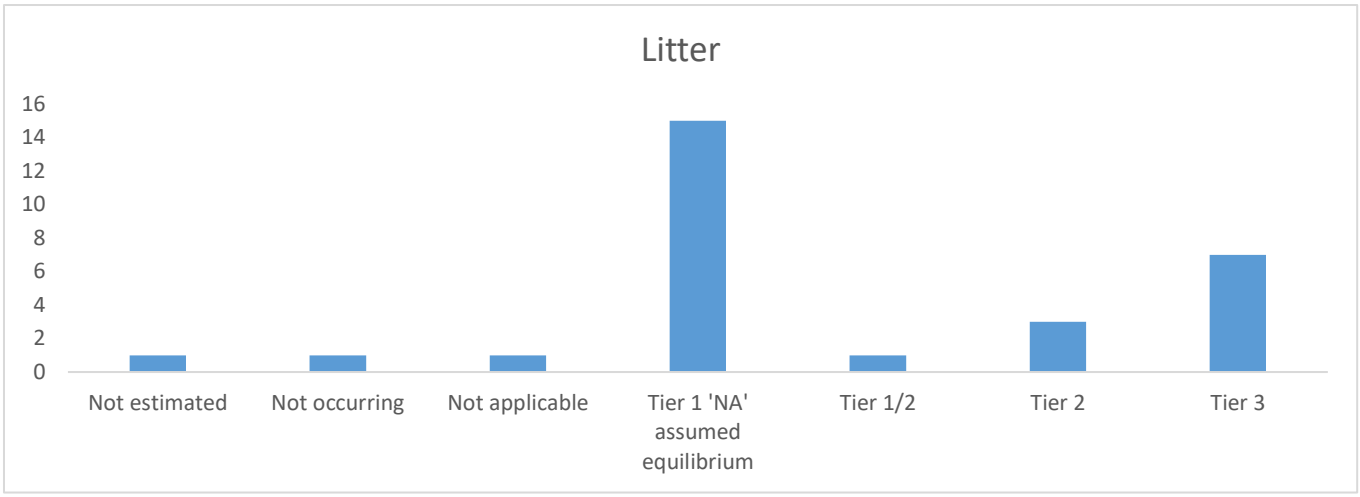

Figure 3- Litter- National Tiers for EU Countries (including Norway) (Brook et al., 2023)

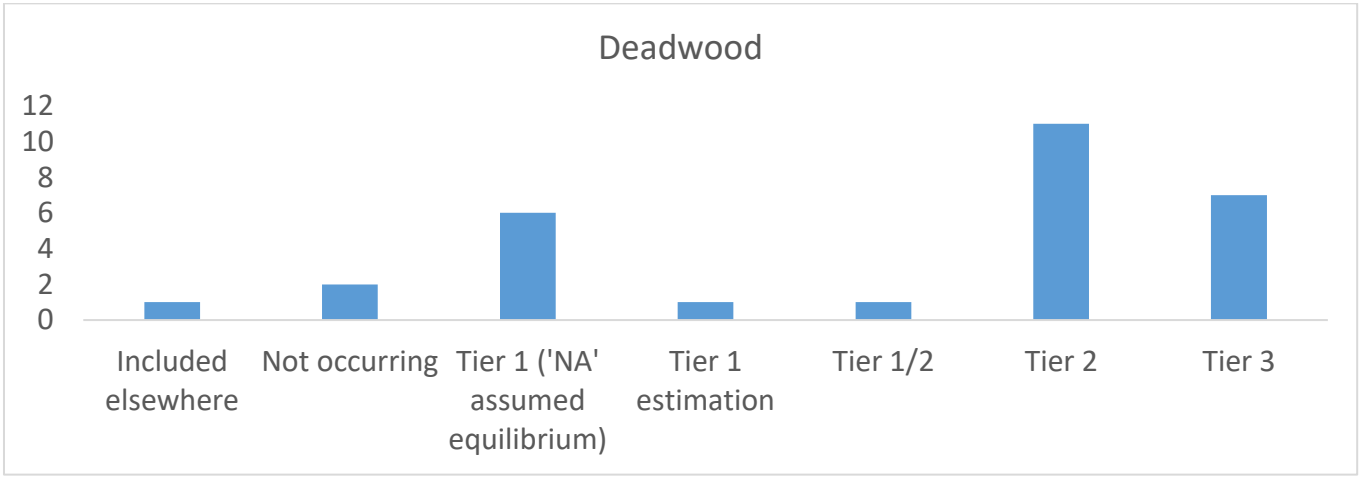

Figure 4- Deadwood National Tiers for EU Countries (including Norway) (Brook et al., 2023)

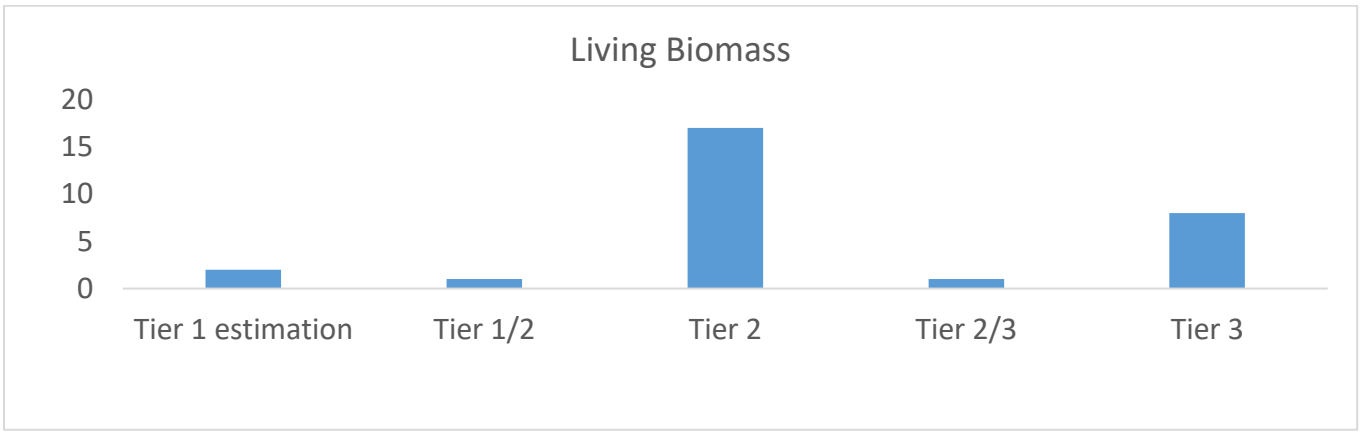

Figure 5- Living Biomass National Tiers for EU Countries (Including Norway and Iceland)- (Brook et al., 2023)

As can be seen from figures 1-4, the tier methods used across EU countries show a wide variation with some carbon pools having a higher accuracy on average than others. For living biomass, the majority of countries use tier 2 highlighting the importance and scale of this carbon pool in national inventories. The same can be seen for the deadwood pool, this is usually derived from living biomass estimates at a national level, although a substantial number of countries classify this pool as not occurring, in equilibrium or using tier 1 estimation methods.

For litter, most countries assume it is in equilibrium, do not estimate it, or class it as not applicable (no mineral soil in forest land). This trend is the same for mineral soil where most countries assume tier 1 or do not report it, with a few countries using models like Carbon Budget Model or Yasso. (Bellassen et al., 2022)estimates that the unreported C stock changes in forest soils in the EU could amount to 45 Mt CO2/yr.

Due to this large 'blind spot' in soil carbon monitoring across the EU, a large increase in accuracy is expected from the common reporting framework utilising a well-defined modelling method and standardised European-wide soil measurement data.

4.1.3 Biomass Conversion and Expansion Factors (BCEF)

A large component of distinction between different methodological tiers are the BCEFs used. Usually, these factors are based on NFI information on growing stock which is then converted to stem biomass using wood density information, to whole AGB using expansion factors and then to whole tree biomass using root-shoot ratios. These series of steps can be detailed in equation 2.8 from Chapter 2, Volume 4 of the 2006 IPCC Guidelines.

EQUATION 2.8
ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS
IN LAND REMAINING IN THE SAME LAND-USE CATEGORY (STOCK-DIFFERENCE METHOD)

$$\Delta C_B = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \qquad \text{(a)}$$

where

$$C = \sum_{i,j} \{A_{i,j} \bullet V_{i,j} \bullet BCEF_{S_{i,j}} \bullet (1 + R_{i,j}) \bullet CF_{i,j}\} \qquad \text{(b)}$$

ΔC_B = annual change in carbon stocks in biomass
$C\ t_2$ = total carbon in biomass for each land sub-category at time t_2, tonnes C
$C\ t_1$ = total carbon in biomass for each land sub-category at time t_1, tonnes C
C = total carbon in biomass for time t_1 to t_2
A = area of land remaining in the same land-use category, ha (see note below)
V = merchantable growing stock volume, $m^3\ ha^{-1}$
i = ecological zone i (*i* = 1 to *n*)
j = climate domain j (*j* = 1 to *m)*
R = ratio of below-ground biomass to above-ground biomass, tonne d.m. below-ground biomass (tonne
d.m. above-ground biomass)$^{-1}$
CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$
BCEFS = biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass, tonnes above-ground biomass growth (m^3 growing stock volume). However, if BCEFS values are not available and if the biomass expansion factor (BEFS) and Wood Density (D) values are separately estimated,

Equation 1- Carbon stock equation IPCC 2006 Good Guidance

While all countries, except one, use country specific values for growing stock, there is a wide variety of usage for BCEF with countries employing default values from the 2006 Good Guidance, country specific values, model calibrated values or values from other countries with similar environments. Additionally, six countries use a combination of Biomass Expansion Factor (BEF) and Density (D) values when BCEF values are unknown. The use of default BCEFs represents a large source of uncertainty in reporting biomass carbon stock changes given the wide range of values.

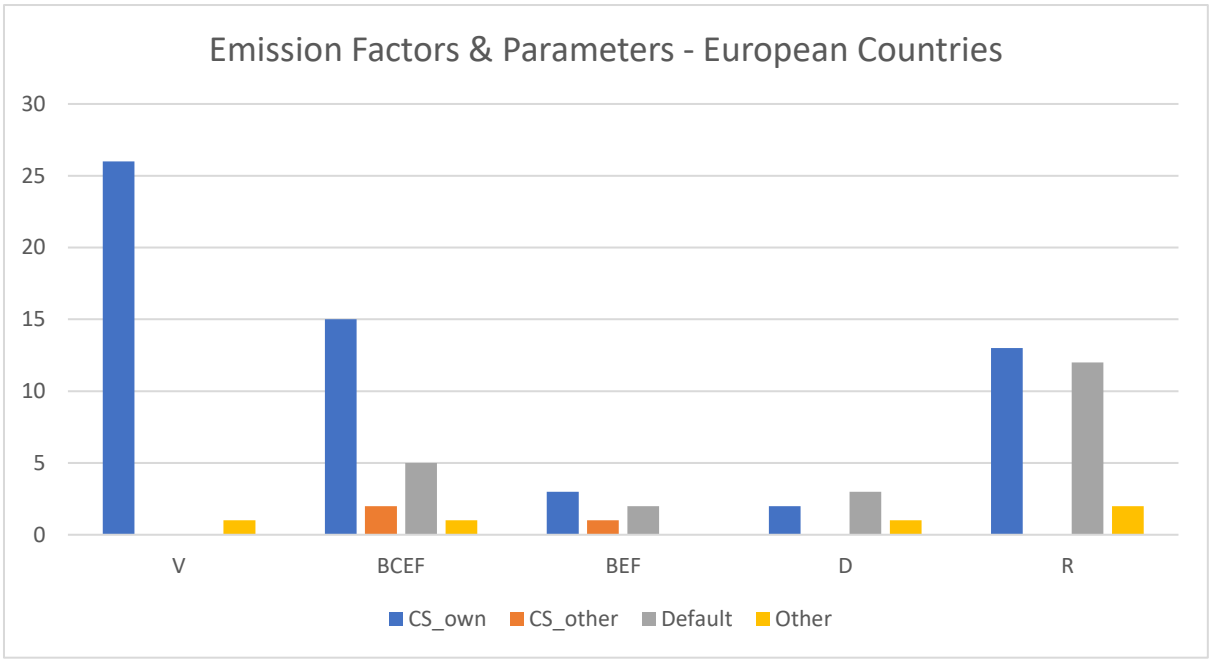

Figure 6- Emission Factor and Parameters- European Countries Count
V- Volume,
BCEF- Biomass Conversion an Expansion Factors
BEF- Biomass Expansion Factors
D- Wood Density
R- Ratio of below-ground biomass to above-ground biomass
CS- Country Specific
(Brook et al., 2023)

4.2 Comparison between PathFinder definitions and National Inventory definitions

Definitions of carbon pools and land types also vary between countries. While no quantitative comparisons have been made to determine the magnitude of differences due to variations, a descriptive comparison has been included to highlight the differences used by the countries.

4.2.1 Forest Definition

Annex II of the LULUCF Regulation defines specific parameters of forest definitions for each Member State. The parameters are minimum values for forest area, tree crown cover and tree height. Areas range from a minimum of 0.05 ha for the Czech Republic and Austria to 1.0 ha for Spain and Malta. Minimum tree crown cover ranges from 10% to 30% and minimum tree height is specified as either 2, 3 or 5 m. Additionally, the definition also includes complementary qualitative criteria such as counting unstocked forest area or areas with young trees yet to reach the threshold height (On the Inclusion of Greenhouse Gas Emissions and Removals from Land Use, Land Use Change and Forestry in the 2030 Climate and Energy Framework, and Amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU, 2018).

While there are some differences, the country's own definitions appear to be generally consistent with the FAO definition, as they use similar parameters (area, height, crown cover) within ranges that overlap or are close to the FAO thresholds, Alternatively, the UNFCCC defines thresholds of 0.5–1.0 ha forest land, 10–30% tree canopy cover and 2–5 m of tree height and does not consider land use. The main difference is that some countries allow for smaller minimum areas and lower minimum heights than the FAO definition.

In comparison, the PathFinder models use a definition of forests as per the FAO which is 'Forests are lands of more than 0.5 hectares, with a tree canopy cover of more than 10 per cent, which are not primarily under agricultural or urban land use'. The overall effect of different forest definitions on carbon stock changes at the EU level is difficult to assess because it depends on several factors (e.g., land fragmentation, land use change frequency, transition period etc) but is considered small (EEA, 2023).

4.2.2 Managed and Unmanaged Forest

The IPCC Guidelines state that countries should report on figures only for managed land. This is defined as 'land where human interventions and practices have been applied to perform production, ecological or social functions'. The idea behind this definition is the majority of anthropogenic GHG fluxes (direct or indirect) take place on managed lands and that the net contribution from natural effects is negligible over time. Carbon stock changes from unmanaged lands are not reported in inventories as they are assumed to be non-anthropogenic.

Given the flexibility of this definition, there have been discrepancies in emissions between national inventories and global models which are used to assess historical emissions and Integrated Assessment Models (IAMs) for exploring scenarios and pathways of future changes. Further research has shown that when using the global mapping dataset for 'Intact Forest Landscape' there is a good match between what countries call managed-forest and non-intact forest across the globe with very little 'intact forest' in Europe (Grassi et al., 2021). For this reporting framework it is assumed that all forest land in EU countries is considered managed and hence reported in the LULUCF inventory.

4.2.3 Biomass

The harmonised definition for AGB biomass includes all aboveground compartments of the living trees, namely the aboveground part of the stump, the stem from stump to top, dead and living branches, and foliage (Avitabile V et al., 2020). This definition is used by PathFinder models to account for the aboveground biomass estimates, excluding trees below 1.3m. In comparison, countries reporting on AGB biomass definitions in their NIRs usually measure trees that meet minimum thresholds for diameter-breast height, or only include merchantable volume (tree stem and branch) excluding other vegetation of the tree.

Concerning dead organic matter, the inventories usually differ between the height/length of the wood and decay times. Currently, there is no standard definition with research concluding that' considerable harmonisation work yet remains' (Rondeux et al., 2012) while other analyses demonstrate that stumps are a considerable part of deadwood biomass whereas only around 60% of surveyed countries collect data as part of the NFIs (Didion & Abegg, 2022). The same can be said for the litter carbon pool, where countries report litter of varying dimensional thresholds, or collating all non-living biomass that is not already formed as part of another class. In comparison, the soil model uses different types of litter inputs including Foliar litterfall (leaves and needles) non-foliar litterfall (fine branches < 2 cm diameter) and Fine roots (< 2 mm diameter).

For soil organic carbon, the Yasso model estimates organic carbon stocks in mineral soil up to a depth of 100cm. In comparison, national inventories usually assess carbon stocks up to a depth of 30-40 cm with some countries up to a max depth of 50 cm. Given the large difference between the model and inventories, it would be expected to see a larger, but consistent, estimate of organic stocks in mineral soils, as compared to the inventory submissions.

The impact of the estimates of such variability in definitions, even if difficult to assess in quantitative terms, is considered small (EEA, 2023).

4.3 Stock Difference or Gain Loss Method

When calculating carbon flux estimates for most carbon pools, countries either use the stock difference method or gain-loss method. Both methods arrive at the same result, however, depending on resources, land area and carbon pool, one method is usually preferred over the other.

- Stock difference: This method is a simple calculation of measuring a carbon pool stock at two different points in time and then working out the difference. The result is the change in carbon stock.
- Gain-Loss method: This method works out the gains (growth rates) and losses (harvests, natural disturbances etc) from the carbon pool separately. The net sum of these two values results in the change in carbon stock.

While these methods don't correspond exactly to tier levels, the gain-loss method can be applied across all tiers while the stock difference method is usually applied at tiers 2 and 3 due to the increase in accuracy needed from data collection.

Table 5- (EEA, 2023)

Country	**IPCC method**
Austria	Gain-loss
Belgium	Stock-difference
Bulgaria	Stock-difference
Croatia	Gain-loss
Cyprus	Gain-loss
Czechia	Gain-loss
Denmark	Stock-difference
Estonia	Stock-difference
Finland	Gain-loss
France	Gain-loss
Germany	Stock-difference
Greece	Stock-difference
Hungary	Stock-difference
Ireland	Gain-loss
Italy	Gain-loss
Latvia	Gain-loss
Lithuania	Stock-difference
Luxembourg	Gain-loss
Malta	Gain-loss
Netherlands	Gain-loss
Poland	Stock-difference
Portugal	Gain-loss
Romania	Gain-loss
Slovakia	Gain-loss
Slovenia	Stock-difference
Spain	Stock-difference
Sweden	Stock-difference

Given that that the IPCC does not specify which method should be used (the guideline only states that 'neither over nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable' (IPCC, 2003)) countries in the EU have an even split between employing the two methods and between the various carbon pools, with both methods accruing relative uncertainty from sampling designs methods and statistical model errors (Röhling et al., 2016).

Estimates from PathFinder models separate the gains and losses for each of the carbon pools, thereby following the gains-loss method. For policymakers, the reporting of gains and losses provides the necessary granularity for identifying short-term trends, such as extreme weather events or changes in forest management practices. This offers a more detailed insight into year-to-year changes, unlike the stock-difference method which fails to capture inter-annual variability. The more frequent updating of data also allows timely and targeted interventions, adaptive management strategies and accurate analysis of policy effectiveness which is crucial in the changing context of climate change and meeting accounting targets.

5. Comparison between PathFinder Approaches and Inventories Estimates

While the method of generating estimates using biomass models have been established on trial run data, quantitative comparisons between the national inventories and the PathFinder approach have yet to be carried out as NFI data is still expected to be captured and processed. Once estimates are generated for biomass stock changes, a full comparison can be carried out to determine the impacts on reported emissions at the EU and national levels.

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