New FAO estimates of net forest emissions and removals, 1990-2025

Francesco N. Tubiello[1], ~~Anssi Pekkarinen[2],~~ Anne Branthomme[2], ~~Michelle Piccoli[1],~~ Griffiths Obli-Laryea[1], Michelle Piccoli[1], Nidal Ramadan[1], Rocio Danica Condor[2], Nathan Wanner[1], ~~and Giulia Conchedda[3]~~Rachele Brivio[1], Giulia Conchedda[3] and Anssi Pekkarinen[2]

[1]Statistics Divis~~5~~ion, Food and Agriculture Organization of the United Nations, Rome, 00153, Italy

[2]Forestry Division, Food and Agriculture Organization of the United Nations, Rome, 00153, Italy

[3]Land and Water Division, Food and Agriculture Organization of the United Nations, Rome, 00153, Italy

Correspondence to: Francesco N. Tubiello (francesco.tubiello@fao.org)

Abstract. The FAO net forest emissions/removals estimates were further developed and updated using as input ~~FAOSTAT statistics~~new ~~of net forest emissions and removals were updated using the most recently available data from the~~ data ~~Global FAO Forest Resources Assessment (FRA)~~on ~~.~~ forest land area and carbon stock collected from countries through the 2025 Forest Resources Assessment. Unlike previous versions, the FAO estimates were expanded to reflect carbon stock changes not only in living biomass, but also in litter, dead wood and soils. Averaged over the most recent decade 201~~5~~6-2025, the FAO results indicated strong removals on forest land, ranging from -3.6 to -6.0 Gt CO_2 yr^{-1}—with lower and upper boundaries reflecting inclusion of stock change for living biomass only or for all pools. The forest removals were partially counterbalanced by~~the FAO estimates show world totals net removals on forest land -4.3 Gt CO_2 yr^{-1}, partially offset by net~~ emissions from net forest conversion of 2.8 to 3.8 Gt CO_2 yr^{-1},—used herein as a proxy for deforestation~~—a proxy for deforestation—of +3.82 Gt CO_2 yr^{-1}~~. Furthermore, ~~The data also suggested a reduction over time of the carbon sink in Annex I countries, by about one-third compared to the earlier 2001-2010 period..~~ Annex I (AI) and non-Annex I (NAI) countries ~~equally~~ contributed equally to ~~removals~~ removals on ~~on~~ forest land, whereas 90% of emissions from net forest conversion were generated in ~~, whereas~~ NAI countries~~the later were responsible for about 90% of the world total emissions from net forest conversion—a proxy for deforestation~~. ~~We linked a set of FRA-related data quality improvements to increased data accuracy in the current version, which we further assessed against country data submitted to the United Nations Framework Convention on Climate Change (UNFCCC). We found strong correlations and close agreement between FAO and UNFCCC data for both net forest conversion emissions and forest land removals, indicating consistency of underlying forest statistics and similarity of estimation methods used by the two processes. The data also suggested a reduction over time of the carbon sink in Annex I countries, by about one-third compared to the earlier 2001-2010 period. Although differences between the FAO and UNFCCC datasets were not significant at the 95% CI, we identified a notable gap in removal estimates for forest land in non-Annex I countries, with FAO suggesting a weaker sink of around 1 Gt CO_2 yr^{-1} compared with UNFCCC over the 2016–2025 period.~~ Comparisons to country data submitted to the United Nations Framework Convention (UNFCCC) indicated close alignment with FAO estimates at global, AI and NAI level, including for the world's major contributing countries. Additional comparisons with the Global Carbon Budget confirmed good alignment of the FAO data with major international assessments, showing good agreement at global level while highlighting specific country discrepancies linked to heterogeneous reporting issues to FAO and UNFCCC. At the same time, grouping ~~Our analysis points to clear areas where~~such discrepancies by typology helped to identify

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Formatted: Font: (Default) +Body (Times New Roman), 10 pt areas of possible data quality improvements aimed at better aligning the country forest statistics submitted to both FAO and UNFCCC—needed for ~~data quality can be strengthened, helping countries achieve better alignment in future international reporting~~ the coherent implementation and monitoring of effective mitigation actions. The ~~The FAOSTAT data~~FAO estimates and country data collected from UNFCCC ~~were made available~~ were produced for 194 countries and 42 territories, with regional and global aggregates, in annual timeseries covering the period 1990-2025. They were made available as open access at 10.5281/zenodo.20085666~~10.5281/zenodo.17395879 (Tubiello et al., 2025)~~.

Keywords: Forest emissions and removals, FAO, FRA, carbon stock change, national GHG inventory

1 Introduction

The forest net emissions/removals dataset of the United Nations Food and Agriculture Organization (FAO) was developed over a decade ago as a global knowledge product, providing relevant information on forests contribution to climate change to users worldwide for over 200 countries and territories and a long time-series (Federici et al., 2015; Tubiello et al., 2021). The data are regularly updated in FAOSTAT as part of FAO agrifood systems emissions (FAO, 2022). The FAO estimates are produced directly at national level, using forest area and carbon stock change information officially submitted by countries to FAO via the Forest Resources Assessment (FRA), the longest standing official international forest data collection process in existence today, providing information on a wide range of forest variables (FAO, 2025a). As such, the FAO forest emissions/removals and its underlying input FRA data represent a valuable resource and a practical benchmarking tool for technical expert reviewers and national greenhouse gas inventory (NGHGI) compilers (IPCC, FAO, IFAD, 2015), working under the enhanced transparency framework of the Paris Agreement. As a global knowledge product, the FAO data have been used to identify, contextualize, and better characterize differences observed across published global datasets of land use land use change and forestry (LULUCF) (Nabuurs et al., 2022; Grassi et al., 2023; Lamb et al., 2026). While a recognized contributor to LULUCF analyses provided in previous IPCC reports (Mbow et al., 2019; Nabuurs et al., 2022), recent work had suggested limitations to the applicability of FAO estimates to both country and global assessments, citing for instance boundary and definitional issues related to the IPCC land proxy (Grassi et al., 2023), FRA data quality (Grassi et al., 2022) and completeness of carbon pools (Tubiello et al., 2021). We addressed all three issues in this manuscript, by presenting more detailed analyses based on the new FRA 2025 input data, and importantly by extending the previous FAO approach to allow for inclusion of all carbon pools covered by the FRA, namely not only carbon stock in above- and below-ground living biomass as in previous version, but adding litter, dead wood and soil carbon pools.

~~The FAO Global Forest Resources Assessment (FRA) provides a comprehensive evaluation of forest resources 0and their condition, management and uses, covering critical thematic elements of sustainable forest management (FAO, 2025a). It is the oldest~~ longest standing ~~official international forest data collection process in existence today, with data collected from member countries at regular intervals since 1948, providing information on a wide range of forest variables through a signature database covering over 200 countries and territories. Each assessment is produced as a stand-alone product, enabling revision of past estimates and the updating of the full time series~~

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when new and better data become available. The latest FRA covers the period 1990-2025., over the period 1990-2025. The FAO forest data serve as an authoritative, official source for tracking long-term trends in forest resources and as such are used as key inputs for assessing the state of the planet, for instance in relation to the world's climate and forests (IPCC, 2019; FAO, 2024), relevant sustainable development goals (FAO, 2017) and the global carbon cycle (Friedlingstein et al., 2025). FAO collects forest-relevant statistics through the FRA on a five-year cycle.

Human-driven_ forest land use and change are key determinants of anthropogenic greenhouse gas (GHG) emissions and removals, and as such forest land use data and statistics are critical inputs to quantify emissions from forest. In particular, conversion of forest to other land uses has been estimated under the international reporting process of the UN Framework Convention on Climate Change (UNFCCC),. Ccountries regularly report their forest emissions and removals estimates within the 'forest land' category of the Land Use, Land Use Change and Forest (LULUCF) sector of their National greenhouse gas inventories (NGHGI), following well-established reporting guidelines (IPCC, 2019). Despite much improvement in recent years, including an increase in data provision through more regular Biennial Transparency Reports (BTR) to the UNFCCC, and significant guidance provided to national experts on available input data and estimation tools (e.g., IPCC, FAO, IFAD, 2015; FAO, 2025b), official NGHGI data do not yet possess global and regional coverage in space and time. A number of global datasets and models have therefore emerged over time to consolidatand complementing e country information and to provide global coverage on the forest emissions and removals, and LULUCF more generally, each with a different scope and methodology. The three main such datasets highlighted by most recent IPCC report (Nabuurs et al., 2022) produced a wide range of net LULUCF CO_2 flux estimates, reflecting the different methods used for their construction. Specifically, over the period 2010-2019, the Joint Research Center NGHGI database (JRC NGHGI, Grassi et al., 2022) estimated a net sink on forest land of -6.6 ± 1.2 Gt CO_2 yr^{-1}; instead the Global Carbon Budget Bookkeeping model ensemble data (Friedlingstein et al., 2022) suggested a global net source of +4.5 ± 2.6 Gt CO_2 yr^{-1}; whereas the FAO 2020 (FAO, 2022) indicated a near-neutral flux. Grassi et al. (2022) have since shown that this large gap across the three approaches could be largely reconciled by re-aligning forest land use definitions and associated boundaries, with further differences depending on the degree with which the different methods included or not indirect effects of climate and CO_2 on natural carbon fluxes alongside those directly caused by human activity (Grassi et al., 2023; Roman-Cuesta et al., 2025).

The FAO estimates are disseminated as a global knowledge product, offering valuable insights for a wide range of applications and serving as a practical resource for instance to the technical expert review (TER) under the enhanced transparency framework (ETF) of the Paris Agreement and NGHGI compilers in FAO member countries for the LULUCF sector (IPCC, FAO, IFAD, 2015; FAO, 2025b). FAO estimates represent a valuable benchmarking tool, helping to identify, contextualize, and better understand the sources of differences observed across datasets (Grassi et al., 2022). By offering a consistent, globally comparable reference, the FAO estimates help highlight where methodological choices, data gaps, or reporting practices may be driving divergences, thereby supporting more informed future improvements. First, FAOSTAT is the only global dataset that applies the carbon stock-change approach consistently across all countries and over time, providing a useful complement to other global datasets that rely on the gain-loss method (Harris et al., 2023) or on a mix of IPCC approaches, depending on the NGHGIs used in their construction (Grassi et al., 2023). Second, the FAO emissions/removal

~~estimates are based on a minimum small set of forest related indicators officially set of forest activity data officially submitted by countries to FAO independent of the UNFCCC process.~~

The main goal of this manuscript wa~~i~~s therefore to document the revised FAO ~~2025 update of~~ net forest emissions/removals statistics and to ~~(FAO, 2025c). In doing so, we~~ compar~~e~~e results ~~from~~ to UNFCCC country data and other independent ~~previously disseminated FAO and other authoritative data~~sources disseminated via the Global Carbon Budget (Friedlingstein et al., 2025)~~, identifying~~. In doing so we identified ~~improvements linked to~~ current and future data quality ~~gains~~improvements needed~~, thus clarifying the scope and methods of the FAO data for the scientific community and policymakers~~ to better align relevant international forest data reporting processes aimed at strengthening country data comparability and thus the evidence base for effective climate action.

2. Materials and Methods

The FAOSTAT database on forest emissions/removals (FAO, 2025b) ~~database~~ disseminates FAO estimates and publicly available UNFCCC country data. The FAO net forest emissions/removals estimates were~~is~~ originally developed by Federici et al. (2015) and Tubiello et al., (2021). They are based on a carbon stock change approach (IPCC, 2019)~~,~~, using as input ~~applied to FRA~~ country data on forest area and carbon stock collected by FAO via the FRA. ~~(Federici et al., 2015 Tubiello et al., 2021).~~ The FRA data serve as an authoritative, official source for tracking long-term trends in forest resources and as such are used as key inputs for assessing the state of the planet, for instance in relation to the world's climate and forests (IPCC, 2019; FAO, 2024), relevant sustainable development goals (FAO, 2017) and the global carbon cycle (Friedlingstein et al., 2025). Conversely, ~~Where available, we also collected relevant~~the UNFCCC country data on forest emissions and removals also disseminated in the FAO dataset were collected from publicly available Biennial Transparency Reports (BTRs), ~~and~~ Common Reporting Tables (CRTs) and National Communications (NCs) including –National Inventory Reports (NIRs) (UNFCCC, 2026).

The FRA input data considered herein were submitted to FAO by its member ~~Considering that the underlying equations for emissions/removals estimates were the same as in previous work, we focussed on documenting the main differences between the FRA 2025 and FRA 2020, with specific attention to data quality improvements relevant to the emissions/removals estimates (Grassi et al., 2022).~~

~~C~~countries, ~~submit forest data to FAO~~ following a standardized methodology ~~to ensure~~aimed at ~~provision of traceable, accurate~~transparenc~~y~~~~t~~ and comparab~~le~~ility ~~le forest statistics~~ (FAO, 2025a). FRA data sources may include national forest inventories, remote sensing, administrative data, academic and specialized studies and, in the lack of other data, expert opinion~~, the latter used particularly to fill gaps in specific forest management or socio-economic variables~~. Data quality i~~ncreases~~mprovements ~~with~~ across successive data collection cycles~~,~~ are often the result of relevant capacity development efforts, and may lead to~~often including~~ revisions of entire time series, based on ~~improved~~ the most recent national forest monitoring ~~processes~~data. ~~Concomitantly, the~~The FRA 2025 data coverage was substantially higher compared to previous data collection cycles. It saw the highest country participation (197 national correspondents, up from 187 in 2020), with increased numbers of direct reports. In addition, a greater number of countries—representing over half of the world's forest area—monitored their forests using more sophisticated data collection approaches, including more frequent national forest inventories and remote sensing analysis.

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2.1 ~~FRA input~~Input data

The FRA 2025 data used in this work ~~as inputs~~to estimate the FAO net forest emissions/removals ~~into the FAO estimates~~included ~~included~~: i. *Forest ~~Land~~* area and its two components: *Naturally Regenerating Forest* area and *Planted Forest* area; and ii. *Forest Carbon Stock* and *Forest Carbon Density* for the following carbon pools: *above-ground biomass; ~~and~~ below-ground living biomass*; *litter*; ~~and~~ *dead wood; ~~d~~* and *soil carbon* (FAO, 2025a)~~.~~ ~~FRA 2025 soil carbon data, also available from FAO, were not used in this work because of lower quality.~~.

The UNFCCC data were collected from available submissions to the UNFCCC, including i. *Forest Land* area and, where available, *Managed Forest Land* area; ii. *Deforestation* area; iii. *Emissions/removals on Forest Land*; and iv. *Emissions from deforestation*. We used the same approach of the European Commission Joint Research Center (Melo et al., 2025) for mapping UNFCCC data to the above forest categories (FAO, 2025b). At the same time we made no attempt to gap-fill missing information either statistically or through additional assumptions (i.e., using LULUCF data to infer forest information), resulting in less data points and country coverage than disseminated by the JRC. ~~Where available, we also collected relevant UNFCCC data from Biennial Transparency Reports (BTRs) and Common Reporting Tables (CRTs) (UNFCCC, 2025).~~

The FRA 2025 dataset covered a broader thematic, geographical and temporal coverage~~,~~ compared to the UNFCCC dataset, the former covering~~. FRA data covered all input variables listed above for more than~~ all forest area and carbon stock variables for 194 ~~200~~ countries and 42 territories for the ~~over~~ 1990-2025 period. Conversely the~~, whereas the~~ UNFCCC data covered a similar period (1990-2023) but ~~were~~ with much sparser thematic coverage (Tab. 1). ~~limited to forest land area data, and only for a group of 60-80 countries, albeit regularly increasing over the 1990-2022 period (Tab. 1). This group includes the high-quality data regularly reported to the Convention from its 42 Annex I Parties. While both FRA and UNFCCC forest land area data are typically sourced from national forest inventories and both adhere to the FAO forest land use definitions, it should be noted that under the FRA, countries report their entire forest land area, whereas data reported to the UNFCCC may be limited to managed land for the purpose of carbon accounting. This distinction was less important in countries that already considered their entire forest land area as managed (Tubiello et al., 2021; Grassi et al., 2022). The next two subsections compare FRA 20205 to FAO 2020 data, quantifying differences in absolute terms as well as in relation to the most recent UNFCCC data.~~

Table ~~1~~1~~.~~: Country coverage of UNFCCC ~~countryy data a dat.~~**~~reported to the UNFCCC collected~~**data disseminated in FAOSTAT, 1990-2023.

	~~1990–2022~~		
	n~~N~~	**Min (Year)**	**Max (Year)**
Total countries	136~~7~~	61~~2~~ (1991)	1034 (2015)
AI countries	41~~2~~	40~~12~~ (2023)	41~~12~~ (2022)
NAI countries	95~~5~~	20~~20~~ (1991)	62~~2~~ (2015)
FL area	94~~5~~	55~~6~~ (1991)	81~~2~~ (2020)
NFC area	734	49~~50~~ (1990)	66~~7~~ (2020)
FL emissions	1334	55~~6~~ (1991)	100~~1~~ (2015)

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NFC emissions	80~~1~~	47~~8~~ (1990)	67~~8~~ (2020)
All 4 variables	68~~9~~	42~~3~~ (1990)	64~~5~~ (2021)

Note~~: : The UNFCCC data collected also includes 2023 data, this is excluded since for 2023 we only have data for Annex I countries~~*~~Min values of AI countries exclude 2023, for which only Luxembourg reported data. Monaco only reported null values, hence max values of AI countries is 41 instead of 42~~The USA had not yet reported for 2023, reducing the AI count to 40 for that year. Monaco reports only null values hence the effective number of countries is 41 instead of 42.*

2.1.2 Forest land area

~~While both FRA and UNFCCC forest land area data are typically sourced from national forest inventories and both adhere to the FAO forest land use definitions, it should be noted that under the FRA, countries report their entire forest land area, whereas data reported to the UNFCCC may be limited to managed land for the purpose of carbon accounting. This distinction was less important in countries that already considered their entire forest land area as managed (Tubiello et al., 2021; Grassi et al., 2022).Both~~The FAO world total forest land area (FAO, 2025d) corresponding to the 236 countries and territories covered in this work was 4.2~~1~~ Gha for the year 2025, ~~FRA 2025 and FRA 2020 datasets provided consistent information regarding temporal trends in forest land area—with country data highly correlated (R^2 > 0.9 across the timeseries) and in close numerical agreement. Both sets indicated a world total forest land area of roughly 4 Gha~~with ~~and~~ a ~~mean annual~~net forest area loss of ~~about 200~~nearly 200 Mha ~~during~~ over the period 1990-202~~0~~5 (FAO, 2025d)~~(Tab. 1)~~. ~~The latter was the result of~~This net loss was the result of opposite trends, with the area of naturally regenerating forest decreasing by ~~nearly~~ around ~~290~~ 300 Mha (-5%) ~~while~~ and the area of planted forest ~~area~~ increas~~e~~ing~~d~~ by about ~~100~~ ~~110~~ 10~~2~~0 Mha (~~nearly over~~ +60 ~~70~~%) over the same period.

Country data were highly correlated between FRA 2025 and FRA 2020 (FAO, 2020) (R^2 > 0.9 across the timeseries) and in close numerical agreement with each other. ~~Furthermore, we found that the major updates in reported forest land area in FRA 2025, resulted in better alignment with UNFCCC reporting. For instance, using 2020 as reference year, the most important update was for Argentina, for which forest land area under FRA 2025 was 47 Mha, compared to 48 Mha reported to UNFCCC—whereas it was 29 Mha in FRA 2020. Additional updates included South Africa (revised upwards in FRA 20205, from 17 to 22 Mha; 26 Mha reported to UNFCCC); and Nigeria (revised downwards in FRA 2025, from 22 to 18 Mha; 14 Mha reported to UNFCCC). In fact, we found a strong positive correlation of reported forest land area data between FAO 2025 and UNFCCC very good numerical agreements at country, regional and global level (R^2 = 0.9827) (Fig. 1).Furthermore, we found that the~~In particular, ~~-~~major updates in reported forest land area in FRA 2025, compared to FRA 2020,~~,~~ resulted in better alignment of FAO and~~with~~ UNFCCC country data (R^2 = 0.9473, Fig. 1)~~reporting. For instance, using 2020 as reference year,~~The most important ~~the most important update was for Argentina, for which forest land area~~ of these improvements was Argentina, ~~under FRA 2025 was~~ updated to 47 Mha in FRA 2025 from~~, compared to 48 Mha reported to UNFCCC—whereas it was~~ 29 Mha in FRA 2020—and very close to the 48 Mha reported by the country to UNFCCC. ~~. Additional updates included~~Similar improvements were found for South Africa (revised upwards in FRA 202~~0~~5, from 17 to 22 Mha; 26 Mha reported to UNFCCC); and Nigeria (revised downwards in FRA 2025, from 22 to 18 Mha; 14 Mha reported to UNFCCC). ~~In fact, we~~

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~~**Table 1**. Input data used in the FAO net forest emissions/removals estimates.~~

~~**Data source**~~	~~**Variable**~~	~~**1990**~~	~~**2000**~~	~~**2010**~~	~~**2020**~~	~~**2025**~~
~~FRA 2025~~	~~Countries (n)~~	~~205~~	~~228~~	~~229~~	~~234~~	~~234~~
~~UNFCCC~~		~~62~~	~~74~~	~~79~~	~~80~~	~~-~~
~~FRA 2025~~	~~Forest Land (M ha)~~	~~**4344**~~	~~**4237**~~	~~**4201**~~	~~**4165**~~	~~**4140**~~
	~~*of which*~~ ~~Naturally Regenerating~~	~~4151~~	~~4010~~	~~3931~~	~~3859~~	~~3824~~
	~~Planted~~	~~192~~	~~225~~	~~269~~	~~305~~	~~314~~
~~UNFCCC~~	~~Forest Land (M ha)~~	~~1093~~	~~2437~~	~~2549~~	~~2605~~	~~-~~
~~FRA 2025~~	~~Above- and Below-ground biomass Mt C)~~	~~310~~	~~307~~	~~309~~	~~312~~	~~313~~
~~FRA 2025~~	~~Litter and Dead Wood (Mt C)~~	~~67~~	~~68~~	~~70~~	~~71~~	~~71~~

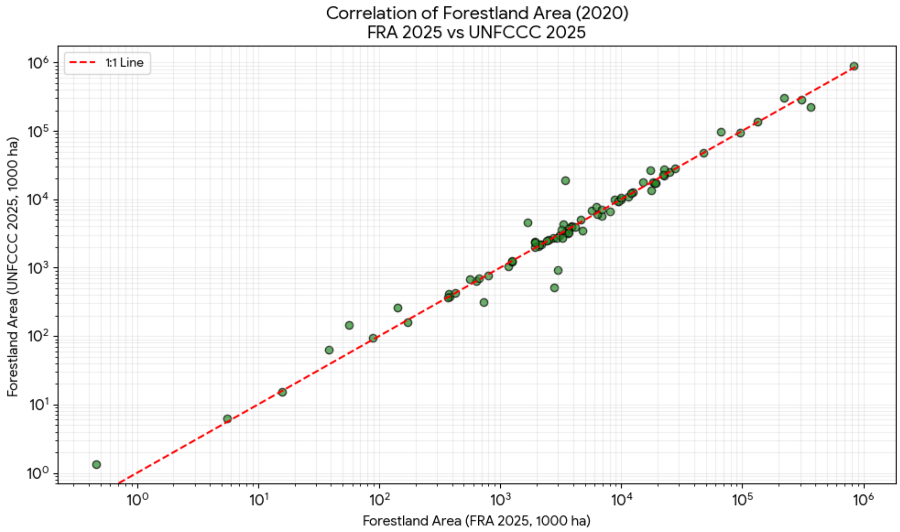

Figure 1. ~~Correlation of log forest land area data reported to both FAO (FRA 2025) and UNFCCC for the year 2020~~Correlation of the log-transformed forest land area (year 2020) reported by countries to both ~~the~~ FAO via the ~~(~~FRA 2025~~)~~ and the UNFCCC ~~for 2020. Each point represents one country.~~. ~~Data for 80 common countries for the year 2020.~~

In line with Grassi et al. (2022) and Melo et al. (2025), we interpreted the UNFCCC area data to refer to managed forest in the following comparisons, unless specified otherwise in the relevant reports. ~~The 80 countries in common between~~Limited to the 81 countries reporting forest area to UNFCCC for the year 2020, the FAO total forest land area ~~FRA 2025 and UNFCCC for the year 2020 represented roughly 60% of the world total forest area~~

~~according to FAO statistics (FAO, 2025d), 100% of area in Europe, nearly 80% in Northern America, Asia and Oceania. Conversely, coverage was poor for Latin America and the Caribbean (20%) and Africa (10%) (Tab. 2). Limited to this set, the FRA 2025 and UNFCCC showed very high agreement~~ was 3.2 Gha, virtually the same as the corresponding UNFCCC total managed forest area. This global agreement masked an important regional feature in the data, showing the Americas to be the only world region where UNFCCC total managed forest area was smaller than FAO total forest area. Conversely, for all other regions the UNFCCC total managed forest areas were larger than FAO (Tab. 2)~~. at world level, as well as for Africa, Europe and Oceania, with relative differences ranging 2-7%, well within the 20% uncertainty of FAOSTAT land use data (Tubiello et al., 2023). The UNFCCC forest land area was, conversely, significantly lower than reported to FAO for Northern America, whether it was higher for Asia and Latin America (Tab. 2).~~

Table 2~~2~~. Global and regional aggregates of ~~available 2020~~ forest ~~land~~ area ~~data for~~reported to ~~FRA 2025~~FAO and UNFCCC for the year 2020.

	Global		**Reporting to both FAO and UNFCCC**			
Region	FAO		FAO	UNFCCC	Difference	
	G~~M~~ha	*n~~N~~ countries*		*Mha*		*~~N~~n countries*
Africa	0.7~~677~~	54	0.2~~221~~	0.3~~287~~	30%	11
Northern America	0.7~~678~~	2	0.7~~678~~	0.5~~509~~	-25%	2
Latin America and the Caribbean~~s~~~~AC~~	1.0~~970~~	~~19~~33	0.7~~676~~	0.6~~555~~	-18%	9
Asia	0.6~~623~~	~~45~~47	0.4~~412~~	0.5~~509~~	24%	20
Europe	1.0~~033~~	~~36~~43	1.0~~028~~	1.1~~105~~	7%	36
Oceania	0.2~~183~~	~~41~~15	0.1~~146~~	0.2~~150~~	3%	3
World	**4.24~~165~~**	**194~~547~~**	**3.2~~161~~**	**3.1~~115~~**	**-1%**	**81**

~~-~~	~~**Global**~~		~~**Overlapping countriesReporting to both FAO and UNFCCC**~~			
~~**Region**~~	~~FAO~~		~~FAO~~	~~UNFCCC~~	~~Difference~~	~~-~~
	~~*Mha*~~	~~*N countries*~~	~~*Mha*~~			~~*N countries*~~
~~Africa~~	~~677~~	~~54~~	~~221~~	~~287~~	~~30%~~	~~11~~
~~Northern America~~	~~678~~	~~2~~	~~678~~	~~509~~	~~-25%~~	~~2~~
~~LAC~~	~~970~~	~~19~~	~~676~~	~~555~~	~~-18%~~	~~79~~
~~Asia~~	~~623~~	~~45~~	~~412~~	~~509~~	~~24%~~	~~3220~~
~~Europe~~	~~1033~~	~~36~~	~~1028~~	~~1105~~	~~7%~~	~~36~~
~~Oceania~~	~~183~~	~~41~~	~~146~~	~~150~~	~~3%~~	~~53~~
~~**World**~~	~~**4165**~~	~~**197**~~	~~**3161**~~	~~**3115**~~	~~**-1%**~~	~~**99281**~~

~~Region~~ ~~FAOSTAT~~ ~~FRA 2025FAO (Corrected)~~

		~~UNFCCC Difference Mha~~		
~~Africa~~Africa	677 (n=54)677	221 (n=11)73	287 (n=11)74	30%1%
~~Northern America~~Northern America	678 (n=2)678	678 (n=2)678	509 (n=2)509	-25% -25%
~~LAC~~LAC	970 (n=19)970	676 (n=7)174	555 (n=7)205	-18%18%
~~Asia~~Asia	623 (n=45)623	412 (n=32)412	509 (n=32)509	24%24%
~~Europe~~Europe	1033 (n=36)1033	1028 (n=36)1028	1105 (n=36)1105	7%7%
~~Oceania~~Oceania	183 (n=41)183	146 (n=5)146	150 (n=5)150	+3%3%
~~World~~World	4165 (n=197)4165	3161 (n=92)2511	3115 (n=92)2552	-1%2%

~~*Notes: The FRA 2025 forest area time series uses data from 236 countries and territories. Carbon estimates are based on data from 235 countries, covering nearly all global forest area; missing values are filled with FAO estimates when countries or territories did not report carbon data.*~~

~~A detailed country level analysis helped to gain insight into possible reasons for the FAO/UNFCCC discrepancy (Tab. 3). It singled out~~ At country level, the FRA 2025 and UNFCCC forest area data were strongly correlated (R^2 = 0.9827, log-normalized) (Fig. 1), with six countries largely driving the observed regional differences (Tab. 3). Specifically, Brazil (-150 Mha), Canada (-140 Mha) and the USA (-25 Mha) alone explained the UNFCCC world total managed forest area being smaller than FAO, in agreement with previous findings (Grassi et al. 2022; Melo et al., 2025). ~~as the largest negative differences between FAO and UNFCCC reported data, indicating that both countries reported managed forest land areas that were substantially lower than total forest land area, in agreement with previous analyses (Grassi et al., 2022). Nigeria (-4 Mha) was the only other country report lower forest land area to UNFCCC compared to FAO. Conversely, the country analysis showed that the remainder of the FAO/UNFCCC discrepancies were in the opposite direction, i.e., larger forest areas reported to UNFCCC than to FAO. Specifically,~~ Conversely, China (+85~~90~~ Mha), Russian Federation (+70 Mha) and Namibia (+60 Mha) ~~and Mexico (+30 Mha)~~ were responsible for~~reported 40% more forest area to UNFCCC, driving the regional discrepancies seen earlier for Asia and Latin America, respectively. In Europe, the Russian Federation reported to UNFCCC an additional 70 Mha (Tab. 3), driving the differences observed for Europe, albeit in relative terms the data represented only 8% more than the area reported to FAO.~~ UNFCCC world total managed forest area being larger than the corresponding FAO forest land area. ~~Larger reported f~~The latter finding~~orest areas compared to those reported to~~ ~~FAO~~ suggest~~ed~~ed ~~that several countries may be including, in their UNFCCC managed land~~

~~areas, areas classified by FAO as 'other wooded land'~~inclusion in NGHGIs of~~,~~ tree covered areas, ~~These are areas with tree cover,~~ such as wooded savannah or tundra, that are typically not considered part of forest under ~~, that do not necessarily meet the FAO~~ FAO definitions (and rather classified as ~~forest land use classification~~'other wooded land.'), but that can be reported as such under UNFCCC definitions. ~~Indeed~~Indeed, the relevant FRA country profiles for the top three countries mentioned above fully confirmed this dynamic. In particular, adding other wooded land to the total FAO forest land area increased Namibia's (managed) forest area by roughly 9 times (Tab. 3). These findings showed that, based on the actual data reported by countries, boundary issues related to smaller reported managed forest area compared total forest land area were limited to a few countries, rather than representing a global feature of UNFCCC vs. FAO statistics.~~. Both under and overreporting of forest area to UNFCCC compared to FAO have consequences for estimations of net forest emissions/removals, as we discuss in the next sections.~~

Table 3~~3~~. Largest absolute differences between FRA and UNFCCC forest area data~~land data~~ for the year 2020 (Gha)

Country	**FAO~~RA 2025~~**	**UNFCCC**	**Difference**
		~~*Mha*~~	
Brazil~~Canada~~	0.5~~369~~	0.3	-0.2~~-143~~
Canada~~China~~	0.4~~219~~	0.2	-0.1~~85~~
U~~USA~~nited States of America	0.3	0.3	-0.0
China	0.2	0.3	+0.1
Russian Federation	0.8~~828~~	0.9	+0.1~~69~~
~~Mexico~~Namibia	0.0~~67~~	0.1	+0.1~~29~~
~~USA~~	~~309~~		~~-26~~
~~Kazakhstan~~	~~3~~		~~16~~
~~France~~	~~17~~		~~10~~
~~South Africa~~	~~22~~		~~5~~
~~Nigeria~~	~~18~~		~~-4~~
~~Australia~~	~~133~~		~~4~~

Note: Brazil's UNFCCC managed forest area was estimated based on the FRA country profile. Results were in line with Melo et al. (2025).

2.1.3 Forest biomass and carbon stock change

~~Similarly to forest land area data, the biomass carbon data of FRA 2025 and FRA 2020 were highly correlated over 1990-2020 (R^2 > 0.9) and in good numerical agreement. Nonetheless there were substantial differences in the underlying trends (with reference to the period 2000-2020).~~ The FRA 2025 carbon stock data showed overall increases in world total above and below-ground living biomass from 2000 to 2025, on average~~While both datasets showed a world total biomass carbon stock (sum of above- and below-ground living biomass pools) of roughly 300 Gt C, the FRA 2025 data indicated~~ by ~~average increases of about~~ 26~~5~~0 Mt C yr^{-1}, whereas the ~~, whereas the~~ FRA 2020 data ~~showed~~ for the same period had shown decreases~~,~~ of ~~roughly~~ -50 Mt C yr^{-1} ~~(FAO 2025a).~~. For the other pools considered in this work, carbon in litter and dead wood increased by 130 Mt C yr^{-1} on average over the same 2000-2025 period, while the soil pool decreased by -76 Mt C yr^{-1} (all changes included losses from net forest conversion to other land use classes).

Of specific interest to this update, the changes in biomass dynamics between the FRA 2025 and FRA 2020 were driven by substantial updates of country biomass stock density values—driven by Russia, USA and China—which substantially improved the alignment of the corresponding FAO net removals with UNFCCC data (see results section), resulting in a stronger forest sink compared to earlier estimates, by about 1 Gt CO_2 yr^{-1}. At the same time, the number of countries reporting constant carbon density values over the entire dataset timeseries, a data quality issue highlighted previously in relation to the FRA 2020 (Grassi et al., 2021), did not decrease in the FRA 2025, applying to nearly 90 countries and territories for a total forest land area of about 900 Mha (although driven by 20 countries covering nearly 90% of that area). As discussed in more detail in the next sections, most countries having constant biomass density values in FRA reported significant carbon sinks in forest land under UNFCCC, implying growing carbon stocks and creating a gap between FAO and UNFCCC estimates of removals on forest land of up to 1.3 Gt CO_2 yr^{-1}. e

~~**With reference to FRA 2020 data, Grassi et al. (2022) had pointed out that constant country values of biomass carbon density were unrealistic, identifying an important link between low quality biomass carbon data and carbon stock change approaches, leading for instance to underestimation of forest sinks in countries where such stocks might in fact be increasing (and vice-versa). We sought to identify such data quality improvements in the FRA 2025, finding substantial data quality improvements across the entire period 1990-2020. Focusing on the period 2011-2020, for which the FRA 2020 had the largest number of imputations, we found that the number of countries with constant biomass carbon density**~~ **had mainly** ~~**reflecting the lack of capacity of many countries to carry out consecutive and consistent forest inventories,**~~ **which s ion** ~~**diminished from 70 in FRA 2020 to 46 in FRA 2025 (Tab. 4).**~~

~~Even more importantly, whereas the 70 low-quality biomass carbon density data in the FRA 2020 corresponded to a total forest land area of 600 Mha, this was reduced to only 20 Mha in the FRA 2025 (Tab. 4). Among the~~

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~~countries with non-zero biomass carbon stock change in the FRA 2025 compared to FRA 2020 were major forest countries, including Republic of Congo (DRC), Indonesia, Angola, Zambia, Papua New Guinea, Gabon, Finland, Central African Republic, Congo, and Nigeria. Conversely, Germany was the only large country with no change in biomass carbon data in the most recent period covered by the FRA 2025, due to a mismatch between its national forest inventory and the FRA data collection cycle. We will document in the next results section the impact of these and additional data quality improvements in the estimated net forest emissions/removals.~~

2.2 Net forest emissions/removals estimation

As discussed, net ~~f~~Forest emissions/removals were estimated using ~~the FRA 2025~~ carbon stock data ~~as new input~~from the FRA 2025 ~~into the same FAO carbon stock change approach developed by Federici et al. (2015) and Tubiello et al. (2021)~~. Whereas previous FAO estimates were limited to stock change in above- and below-ground living biomass pools, this update also included stock change in the litter, ~~and~~dead wood ~~pools~~ and soil carbon pools. This important extension allowed for a better alignment in scope with country inventories, which are expected to include additional pools to increase accuracy, depending on national capacity. In terms of FRA inputs, let A, A^{nr}, A^{pl} be the total area of *forest* and of its two strata, *naturally regenerating forest* and *planted forest*; B_r and $b_p = B_p/A$ be the total carbon stock and carbon density of reservoir *p = above and below-ground living biomass*, *litter*, and *dead wood*. Let furthermore ΔA^{nr}, ΔA^{pl} and CSC_p be the net area change of each forest strata and the net carbon stock change of carbon pool p, computed over the time Δt between two successive FRA data points. With reference to previous work (Tubiello et al., 2021), the total CSC of each pool can be split into two distinct components, specifically carbon stock change due to net forest conversion (to other land uses), NFC—used herein as a proxy for deforestation losses; and carbon stock changes within the remaining forest land, FL (Fig. 2). The ~~Following Tubiello et al. (2021),Briefly, emissions/removals were computed with a minimum set of country-level equations~~ at the country-level, ~~as follows. For any given year and country, let A, A_{nr}, A_{pl} be, respectively, the total *forest land* area, the area of *naturally regenerating forest* and the area of *planted forest*, B the carbon stock and CSC the associated carbon stock change. Let us furthermore denote $b = B/A$ the corresponding carbon density. Following Tubiello et al. (2021), CSC can be split into two separate component fluxes (Fig. 1): NFC, representing fluxes from forest loss referred to as net forest conversion; and FL, representing net fluxes on remaining forest land. The corresponding~~ equations to compute the FAO net forest emission/removal estimates (E/R) for country c and time t, ~~are~~were as follows:

$$CSC_{p,c,t} = \Delta B_{p,c,t}\ ; \quad \text{with } p = \textit{living biomass, litter, dead wood, soil} \tag{1}$$

$$NFC_{p,c,t} = b_{p,c,t} * \Delta A_{NFC\,c,t}\ ; \quad \Delta A_{NFC\,c,t} = \Sigma_A\,[\,\min(\Delta A^{nr}{}_{c,t}, 0) + \min(\Delta A^{pl}{}_{c,t}, 0)] \tag{2}$$

$$FL_{p,c,t} = CSC_{p,c,t} - NFC_{p,c,t} \tag{3}$$

$$E/R^{NFC}{}_{c,t} = -\Sigma_p\,(\,(1-\alpha_p) * NFC_{p,c,t} * 1000 * 44/12\,) / \Delta t \tag{4}$$

$$E/R^{FL}{}_{c,t} = -\Sigma_p\,(FL_{p,c,t} * 1000 * 44/12) / \Delta t \tag{5}$$

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$$E/R^{CSC}_{c,t} = E/R^{NFC}_{c,t} + E/R^{FL}_{c,t} \qquad (6)$$

Where: *CSC*, *NFC* and *FL* were expressed in kt C and E/R were in units of Mt CO_2 yr^{-1}. Annualized emissions were expressed as 10 year (or 5 year) means between FRA periods.

Equations (4)-(6) were needed to transform carbon stock change over given FRA periods into mean annual CO_2 emissions/removals, with the sign used conventionally to consider fluxes from land to atmosphere as positive (corresponding to negative stock change) and vice-versa.

Equation (2) was used to compute net area conversion of forest land to non-forest classes using national statistics, a simple proxy for deforestation in line with approach 1 of the IPCC (2019) guidelines. Our equations, however, track change for two separate strata, *naturally regenerating forest* and *planted forest* area, thus accounting for more nuanced dynamics in the overall carbon fluxes. For instance, the FAO equations could track area decreases and associated carbon losses in natural regenerating forest regardless of overall increases in total forest land area. Conversely, equation (3) could account for increased area of forest plantation and associated carbon sequestration even in presence of overall losses of total forest area. Equation (4) was written to compute emissions to the atmosphere following *NFC* carbon losses, assuming 'instant oxidation' to the atmosphere of carbon in biomass, litter and dead wood, while retaining a portion of the soil carbon lost after transition to the new land use. To this end the coefficient α_p in equation (4~~5~~) represented retention in the destination pool between FRA periods, specifically: α_p =0 for *p* = above and below carbon, litter, dead wood; and α_{soil} =2/3; consistently with the relevant F_{LU} and F_{MG} default coefficients specified in Tab. 5.5 and Tab. 6.2 of the IPCC (2006) guidelines The fluxes estimated between FRA years represented in practice ~~10 year~~10-year transitions (5 years for 2020-2025), mid-way between instant oxidation and the 20 years IPCC default transition recommended for computing soil losses.

T

~~Equations (1)~~ and ~~(2) conventionally assign a positive sign to fluxes from the forest to the atmosphere (emissions) and a negative sign to fluxes in the opposite directions, from the atmosphere to the forest (removals). Additionally, as first noted in Federici et al. (2015), the *FL* fluxes include two distinct processes: biomass carbon density changes on stable forest land area; and biomass stock changes on expanding forest land area.~~ The sums over carbon pools in equations (1)-(6) were used to distinguish among three increasingly complete FAO carbon stock change models: *FAO 1*, for which carbon stock changes were limited to above and below-ground living biomass; *FAO 2*, which included in addition carbon stock change for litter and dead wood; and *FAO 3*, which also included soil carbon stock change, thus taking full advantage of the input FRA data. When presenting results, the corresponding FAO model range was considered appropriate for comparisons to UNFCCC data, given that the underlying NGHGIs were typically compiled by countries using a variety of approaches, dependent on many factors including carbon stock data availability and national capacity (Melo e~~a~~t al., 2025). Conversely FAO 3 was considered biophysically more complete and conceptually better aligned with more complex carbon cycle models, which tended to include all pools. Data for all the three FAO models, as well as relevant UNFCCC country data, were provided as open source at 10.5281/zenodo.20085666. ~~These were not analysed separately in this work. As in previous work the estimated net emissions/removals represented mean annual fluxes between FRA~~ the ~~years~~

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~~1990, 2000, 2010, 2020, and 2025; they were extended for dissemination in FAOSTAT to annual timeseries over the period 1990-2025, by repeating the mean annual flux in each period.~~

~~Finally, emission/removal estimates were computed herein using carbon stock changes in above- and below-ground living biomass, litter and dead wood pools, whereas previous work linked to FRA 2020 and FRA 2015 input data had only included stock changes in the living biomass pools.~~

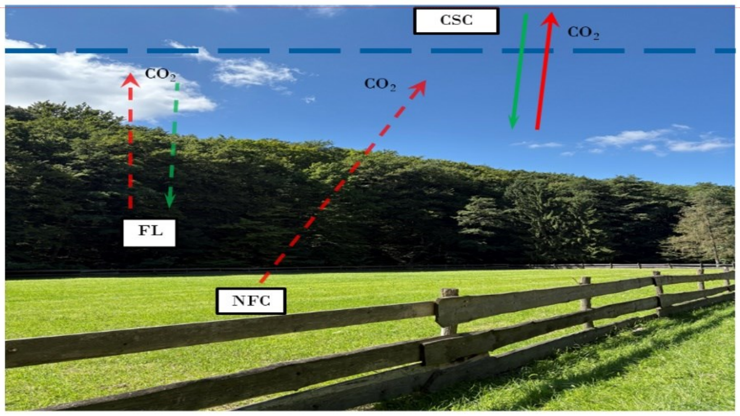

Figure 2~~1~~. Forest fluxes included in the FAO dataset, including carbon stock change (~~FL_Tot~~CSC) and its ~~two~~ component~~s~~ fluxes, net forest conversion~~s~~ (NFC) and forest land (FL).

~~**Finally, emission/removal estimates were computed herein using carbon stock changes in above- and below-ground living biomass, litter and dead wood pools, whereas previous work linked to FRA 2020 and FRA 2015 input data had only included stock changes in the living biomass pools.**~~

2.3~~2.1~~ Limitations and uncertainty

Several limitations to the FAO methodology ~~have been discussed~~were highlighted in previous work (~~Grassi et al., 2022;~~ Tubiello et al., 2021; Grassi et al., 2022~~0~~). A first set referred~~s~~ to ~~the~~ area boundaries, ~~used for their computations,~~ which determine whether the estimated net forest~~resulting~~ emissions/removals can be considered anthropogenic or not. ~~At the outset we note that the FAO methodology follows~~ Following the IPCC land use proxy approach, ~~so that~~we considered all emissions~~/ and~~ removals estimated on ~~a given~~ managed ~~area were considered~~land as anthropogenic, irrespective of direct and indirect climatic and CO_2 effects (IPCC, 2019)~~. At the same time,~~). The critical issue was that the FAO area statistics ~~did not allow to distinguish between managed and unmanaged~~employed in this work referred to total forest land area, implying that some of the FAO estimated fluxes may contain natural components. At the same time however, as discussed previously in methods, we found that most countries reported managed forest area to UNFCCC that was equal to or greater than the FAO total forest land area, thereby annulling in most cases or substantially reducing the perceived mismatch between FAO and UNFCCC area boundaries.

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Furthermore, w~~W~~e had ~~have~~ argued ~~in the past~~ (~~Tubiello et al., 2020;~~ Federici et al., 2015; Tubiello et al., 2021~~215~~) that ~~this affects~~ only a subset of ~~the~~ estimated fluxes depended on managed vs. total forest area boundaries. Specifically, emissions from net forest ~~area loss (defined herein net forest~~ conversion~~)~~, including their indirect climate and CO_2 components, ~~were~~ could be considered anthropogenic ~~by definition,~~ as long as~~because~~ human agency ~~ultimately drives~~ determined the und~~the und~~erlying land use change~~s~~. ~~Directly, mainly via deforestation activities caused by humans. Indirectly, because forest losses, even when caused by natural causes, only become recorded as land use change when reflecting human decisions on land allocation.~~ The same would apply to ~~Direct and indirect climate and CO_2 components~~ removals on forest land due to the establishment of plantations. ~~of net forest conversion emissions can likewise be considered anthropogenic. Conversely,~~ Of the emissions/removals estimated in this work, only a portion ~~emissions/removals~~ on remaining forest land~~, FL, will~~ may have a non-anthropogenic component ~~because the underlying FRA data do not distinguish between managed and unmanaged~~ forest ~~land.~~ ~~. Nonetheless the afforestation component of FL can be considered anthropogenic, for the same reasons put forward above in relation to net forest conversion activities. The only component of FL that will have a mix of anthropogenic and natural fluxes is forest land remaining forest, with Grassi et al. (2022) estimating that on average, 80% of the total forest area is managed, and using this fact to 'correct' natural fluxes in the global carbon cycle (Friedlingstein et al., 2025).~~ We ~~suggest therefore that the non-anthropogenic component of the FAO estimates is quite small in the aggregate and show in the discussion sessions below~~suggest that, based on actual country data comparisons, that the boundaries of FAO estimates and UNFCCC data were in fact very much aligned~~specific country cases that emerge from detailed FAO/UNFCCC comparisons~~.

A second set of limitations in the FAO estimates presented here is the~~ir national~~ 'Tier 1' national level approach with which they were computed, as opposed to higher Tiers methods. We recognize that~~The use of~~ remote sensing and machine learning make already possible today the production of accurate forest estimates at increasingly fine scales, including by FAO (e.g., Mozafari et al., 2023; Araza et al., 2023; FAO, 2024). At the same time, we emphasize that the value of the FAO net forest/emissions dataset ~~is widely recognized as a~~lies in providing a robust and transparent reference for assessing higher-Tier estimates. Its straightforward, reproducible equations, grounded in official national statistics, make it a practical tool for both national compilers, expert reviewers of ~~the~~ NGHGIs and modelers (FAO, IFAD, IPCC, 2015). Nonetheless, using national statistics as input and constant national coefficients has recognized limitations. *First*, estimates of net forest -land area change may systematically underestimate gross forest area changes and associated emissions/removals. We have noted, however (see methods), that the FAO ~~equatoins~~equations~~our methods~~ may limit such bias, by considering the independent losses of ~~treating~~ naturally regenerating forest and planted forest areas ~~separately, each representing good~~ as approximations for national--level gross forest area loss ~~and gains~~. *Second*, ~~the use of initial biomass stock density values to estimate net forest conversion fluxes over a subsequent period would underestimate emissions in countries with increasing growing stocks and overestimate it in countries with decreasing stocks. *Third*,~~ the use of national-level biomass stock density would tend to underestimate net forest conversion emissions in cases when the forest being lost is primary or anyway characterized by biomass densities higher than the national average. *Third*~~*Fourth*~~, net emission/removal estimates on remaining forest land depend strongly on the quality of the underlying biomass carbon density data. As noted by Grassi et al. (2022), missing information on changes over time may~~will~~ generate underestimates of removals in countries with increasing ~~growing stocks~~carbon stock densities, while ~~and~~ overestimat~~ing~~e ~~of~~ emissions in countries with decreasing ~~forest degradation~~forest biomass

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densities. Furthermore, in relation to newly established forest areas, the use of national biomass stock density values ~~would~~ may overestimate removals in countries ~~where the~~with newly ~~established~~ forest~~s~~s ~~of~~ ~~carried~~ lower carbon density than the national average, and vice-versa. A final limitation of ~~our~~ the FAO estimates was ~~is that they do not consider changes in~~related to the inclusion of additional carbon pools, because while adding biophysical completeness to the underlying FAO carbon stock change model, they would tend to increase uncertainty. In particular, t~~the soil carbon pool. Inclusion of soil carbon pool in the FAO equations would likely produce stronger sinks on forest land in countries with long-term growing biomass trends, however such computations require accurate data, given the large size of this pool. Conversely the~~he FRA 2025 soil carbon data had ~~lower data quality~~ limited coverage and consistency compared to the other pools and ~~had to be~~were gap-filled with published~~existing~~ s~~S~~oil o~~O~~rganic c~~C~~arbon maps ~~used herein and were therefore not used~~(FAO, 2025a). In relation to the soil carbon pool, we note that the FAO equations for *NFC* used a constant coefficient $\alpha_{soil} = 2/3$ for retention of soil carbon across all possible net forest conversions (see methods). The value chosen was the recommended IPCC default for transitions to annual cropland in temperature zones, while lower default coefficients ($\alpha_{soil} = 0.5$-0.6; but with uncertainties of 60%) were recommended for tropical countries. This implied in principle that the FAO *NFC* emissions estimates may be underestimated in tropical countries. However, FAO land use change data (FAO, 2025c) suggests that a substantial portion of net forest conversion in the tropics occurs through conversion to either grassland (Latin America) or permanent crops (West Africa and Southeast Asia), for which the default IPCC coefficients are $\alpha_{soil} = 1$, hence reducing the possible overestimation. Finally, we note that FRA data corresponding to the year 2025 were country projections, typically performed via linear trend extrapolation or carry forwards of the last available observation. Therefore, our estimates of emissions/removals over the period 2020-2025, which we report nonetheless below when discussing the most recent global and regional results, should be considered provisional, until the next FRA update. These issues were less important when reporting trends over the last decade 2015-2025 or when averaging over 2001-2023 for FAO/UNFCCC comparisons.

T~~T~~he long list of limitations discussed ~~listed~~ above ~~were reflected in~~implied that the FAO estimates were characterized by substantial ~~high data~~ uncertainty. We followed Tubiello et al. (2021) in assigning ~~used herein the~~ 50% (95% CI) uncertainty to~~in~~ all FAO emissions/removals components derived in this work, ~~previously by Tubiello et al. (2021), noting these were~~ consistently with established literature on LULUCF (e.g., IPCC, 2022; ~~with those used in the literature (~~Friedlingstein et al., 2025~~5; IPCC, 2022~~).

We conclude by noting that according to the relevant guidelines on communicating uncertainty published by the International Bureau of Weights and Measures (BIPM et al., 2008), the level of uncertainty underlying measured or estimated quantities determines the precision –i.e., the number of significant figures—with which results should be communicated. Generally, uncertainties of 50% imply use of at most two significant figures in reporting estimated means and their confidence intervals. We applied this guidance through this paper. Finally, we used the upper and lower FAO stock change models estimates to qualitatively provide uncertainty ranges for comparing FAO to UNFCCC data. This range roughly coincided with roughly 30% uncertainty bounds around FAO 2 estimates.

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2.4~~3~~ Data Availability: Structure of FAOSTAT dataset

The FAOSTAT dataset cover the period 1990-2025 for 194~~5~~ countries and 42~~39~~ territories. Aggregates were computed for 22 sub-regions, 5 continents and 8 special aggregates, including UNFCCC Annex and non-Annex I, OECD, least-developed countries, small island developing states. The FAO dataset further included~~s~~ available ~~National GHG Inventory (NGHGI)~~ country data submitted to the UNFCCC. ~~–~~ T~~via Biennial Update Reports (BURs) and Biennial Transparency Reports (BTRs). T~~hey were disseminated without interpolation of missing values, resulting in nearly 9~~4~~000 data points for a combined total of 137~~94~~ countries over the period 1990-2023. ~~Of these, 42 were AI and 52 NAI countries.~~ The FAO 2025 net forest emissions/removals and corresponding UNFCCC data are available as open data via Zenodo (Tubiello and Obli-Laryea ~~et al.~~, 2026~~5~~), with DOI 10.5281/zenodo.20085666~~10.5281/zenodo.17395879~~. Limited to results for living biomass, they were also available via FAOSTAT (FAO, 2026).

3. Results

~~The updated FAO 2025 estimates provide a comprehensive overview~~We provided below a synthesis of ~~of~~ the new FAO ~~net forest emissions and removals~~dataset, by presenting results aggregated at World, Annex I (AI) and non-Annex I (NAI) levels, as well as by FAOSTAT region and by major contributing countries ~~for the period 1990-2025~~. In doing so, we first presented an overview of net forest emissions/removals for the full geographical country coverage characterizing the FAO estimates, followed by comparisons to UNFCCC over the more limited geographical scope noted earlier. For World, AI, NAI and country data we discussed the full range of results across the FAO carbon stock change models FAO 1, FAO 2 and FAO3 presented in the previous section, while for simplicity we only reported FAO 3 results for regional storylines. ~~, covering carbon stock change (CSC), net forest conversion (NFC) and forest land (FL) fluxes at global, regional and country level. Below, we present results that include changes in living biomass, litter, and dead wood~~ and soil ~~carbon pools (Tab. 5), complementing the biomass-only estimates discussed in a recent FAOSTAT brief (FAO, 2025b)~~We did not report estimates together with their uncertainty values. While each estimate carried in principle 50% uncertainty, we used the range of the three FAO models to provide a heuristic, practical if imperfect way to communicate uncertainty. ~~The next section compares these findings with the previous update based on FRA 2020 and adds a comparison with UNFCCC country data, offering further insight into how FAO estimates can effectively complement established assessments, building on earlier work (IPCC, 2022).~~

~~3.1 Carbon Stock Change net emissions/removals~~

~~The FAO data show that world total carbon stock change (CSC) was positive in the 1990s (1991-2000) but has since stayed negative, indicating that forests were globally net sinks of atmospheric CO_2, sequestering more than 1 Gt CO_2 yr^{-1} in recent decades (Fig. 1, Tab. 5). This overall net sink was the result of strong removals on forest land being not fully counterbalanced by net forest conversion emissions. For instance, in 2016-2024 the former indicated a mean sink larger (in absolute terms) than -4 Gt CO_2 yr^{-1}, whereas the latter were about 3 Gt CO_2 yr^{-1}. Carbon stock change was substantially negative in Annex I (AI) countries over the entire period of study, albeit decreasing in strength by nearly 1 Gt CO_2 yr^{-1} over time. Conversely, while remaining positive over the entire~~

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~~period in non-Annex I (NAI) countries, it strengthened significantly for this group since the 1990s. Regional values of CSC showed opposite regional trends (Fig. 3): the overall carbon stock change resulted in forests in the Americas and Africa being consistent net sources over the entire period (+0.9 and +0.6 Gt CO_2 yr^{-1}, respectively, in 2016-2025), whereas they acted as strong sinks in Europe and Asia (-1.5 and -1.1 Gt CO_2 yr^{-1}, respectively). Forests in Oceania switched over the period considered from a net source (about +40 Mt CO_2 yr^{-1} in the 2010s) to a net sink (-30 Mt CO_2 yr^{-1} in 2021-2025). In terms of climate zones covered in the FRA (not shown), in~~), in ~~the more recent period 2016-2025, boreal and temperate forests acted as sinks (-1 Gt CO_2 yr^{-1} each) while tropical forests were net sources (+1.8 Gt CO_2 yr^{-1}).~~

~~**Table 5**. FAO 2025 net forest emission/removal estimates 1990-2025 (Mt CO_2 yr^{-1}).~~

		~~**1991-2000**~~	~~**2001-2010**~~	~~**2011-2015**~~	~~**2016-2020**~~	~~**2021-2025**~~
~~**Carbon stock change**~~	~~World~~	~~851~~	~~-1488~~	~~-1858~~	~~-1222~~	~~-1100~~
	~~Annex I~~	~~-2671~~	~~-3104~~	~~-2705~~	~~-1971~~	~~-1882~~
	~~Non-Annex I~~	~~3522~~	~~1617~~	~~847~~	~~750~~	~~782~~
	~~Africa~~	~~1018~~	~~972~~	~~1775~~	~~972~~	~~603~~
	~~Americas~~	~~1404~~	~~399~~	~~-247~~	~~673~~	~~881~~

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	~~Asia~~	~~1504~~	~~-986~~	~~-1223~~	~~-1491~~	~~-1079~~
	~~Europe~~	~~-1763~~	~~-1935~~	~~-1635~~	~~-1391~~	~~-1474~~
	~~Oceania~~	~~42~~	~~61~~	~~-30~~	~~14~~	~~-31~~
~~Net forest conversion~~	~~World~~	~~5699~~	~~3547~~	~~3276~~	~~3065~~	~~3176~~
	~~Annex I~~	~~460~~	~~150~~	~~68~~	~~335~~	~~296~~
	~~Non-Annex I~~	~~5237~~	~~3397~~	~~3209~~	~~2729~~	~~2880~~
	~~Africa~~	~~1056~~	~~1048~~	~~1354~~	~~900~~	~~765~~
	~~Americas~~	~~3288~~	~~2177~~	~~1526~~	~~1845~~	~~2069~~
	~~Asia~~	~~1227~~	~~165~~	~~333~~	~~233~~	~~282~~
	~~Europe~~	~~42~~	~~58~~	~~57~~	~~61~~	~~54~~
	~~Oceania~~	~~86~~	~~100~~	~~7~~	~~25~~	~~6~~

~~**Forest Land**~~	~~World~~	~~-4847~~	~~-5035~~	~~-5134~~	~~-4287~~	~~-4276~~
	~~Annex I~~	~~-3131~~	~~-3254~~	~~-2772~~	~~-2307~~	~~-2178~~
	~~Non-Annex I~~	~~-1715~~	~~-1780~~	~~-2362~~	~~-1980~~	~~-2098~~
	~~Africa~~	~~-38~~	~~-75~~	~~-77~~	~~73~~	~~-162~~
	~~Americas~~	~~-1884~~	~~-1777~~	~~-1772~~	~~-1172~~	~~-1188~~
	~~Asia~~	~~-1076~~	~~-1150~~	~~-1557~~	~~-1724~~	~~-1361~~
	~~Europe~~	~~-1805~~	~~-1993~~	~~-1692~~	~~-1452~~	~~-1528~~
	~~Oceania~~	~~-44~~	~~-39~~	~~-37~~	~~-11~~	~~-37~~
		1991-2000	2001-2010	2011-2020	2021-2025	
Carbon stock change	World	3549	-1438	-1216	-523	
	Annex I	-3094	-4117	-3121	-2353	
	Non-Annex I	6644	2680	1905	1829	

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~~Net forest conversion~~	~~World~~	~~7123~~	~~4329~~	~~3922~~	~~3838~~
	~~Annex I~~	~~601~~	~~217~~	~~275~~	~~368~~
	~~Non-Annex I~~	~~6520~~	~~4111~~	~~3647~~	~~3470~~
~~Forest Land~~	~~World~~	~~-6421~~	~~-7329~~	~~-6643~~	~~-5687~~
	~~Annex I~~	~~-3977~~	~~-4467~~	~~-3545~~	~~-2864~~
	~~Non-Annex I~~	~~-2441~~	~~-2862~~	~~-3097~~	~~-2823~~

3.1 Global and regional results

3.1.1 FAO estimates

The FAO data showed increasing carbon stocks, hence negative carbon stock change fluxes, for all FRA periods except for 1990-2000, indicating that since the year 2000 forests acted globally as net sinks of atmospheric CO_2, sequestering up to -1.8 Gt CO_2 yr^{-1} on average in 2020-2025—the most recent period in the FAO estimates (~~Fig. 3,~~ Tab. 4). The two separate components of *CSC* defined earlier further showed strong carbon sequestration on remaining forest land, with *FL* removals of up to~~of about~~ -5.7~~6~~4 Gt CO_2 yr^{-1}, compared to losses from net forest conversion, *NFC*, of ~~nearly 4~~up to 3.8 Gt CO_2 yr^{-1}. At the same time, the *CSC* fluxes were consistently negative for the entire time series for AI and positive for NAI countries. Regional values showed opposite trends, with *CSC*~~:~~ in the

~~**Figure 3.** Annual net forest emissions/removals by FAO regions in the period 1990-2025.~~

Americas and Africa, indicating net emissions over the entire period, about +~~0.9~~1.5 ~~1.4~~Gt CO_2 yr^{-1} on average for 2020-2025. Conversely, Europe and Asia were net overall sinks, about -2.0~~1.5~~ ~~7~~Gt CO_2 yr^{-1} in the most recent period. Forests in Oceania switched from small net sources in the 2010s to net sinks ~~65~~in 2020-2025.

With respect to emissions from net forest conversion, the FAO estimates showed substantial decreases over time, globally from 5-7 Gt CO_2 yr^{-1} on average during 1990-2000 to 3-4 Gt CO_2 yr^{-1} in 2021-2025 (Tab. 4; Fig 3a). This trend was almost entirely driven by NAI countries, responsible for about 90% of the world total net forest conversion emissions. Regionally, the Americas (2.4 Gt CO_2 yr^{-1} during 2020-2025) and Asia (0.4 Gt CO_2 yr^{-1}) were the ~~amin~~main drivers of the global trends in *NFC*, each showing reductions in deforestation emissions greater than 1 Gt CO_2 yr^{-1}. The FAO data furthermore showed that in Africa *NFC* increased over time, reaching a peak of about 1.8 Gt CO_2 yr^{-1} during 2010-2015, then decreasing to less than 1.0 Gt CO_2 yr^{-1} in 2020-2025. Europe and Oceania were minor global contributors.

With respect to net emissions/removals on forest land, the FAO results showed substantial carbon sinks on remaining forest land, with *FL* as strong as -7.1 Gt CO_2 yr^{-1} on average during 2000-2010 and decreasing in subsequent FRA periods, to -5.7 Gt CO_2 yr^{-1} on average during 2021-2025 (Tab. 4, Fig. 3a). The global *FL* net removals were equally divided between AI and NAI aggregates in the most recent period, about -2 to -3 Gt CO_2 yr^{-1} on average over 2020-2025 (Tab. 4), whereas in earlier periods removals on forest land were stronger in AI countries. Results showed consistent regional sinks over the study period except for Africa. Specifically, Europe, Asia and the Americas had large sinks on forest land, with Europe the most substantial at about -2 Gt CO_2 yr^{-1} in 2020-2025. Additionally, the FAO data suggested opposite regional trends, with decreased by about 15% in Europe and by nearly 40% in the Americas from 2000 to 2025 but increases of 30% in Asia. Africa and Oceania had comparatively small net fluxes on forest land, with less ~~notablet~~notable trends.

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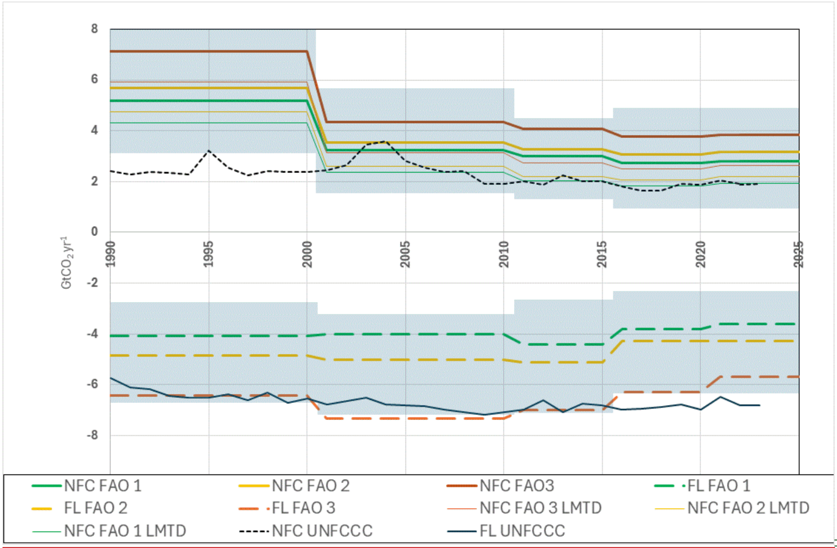
Table 4. FAO 2025 net forest emission/removal estimates (Gt CO_2 yr^{-1}) corresponding to FRA periods, by FAO stock change model.

		1990-2000			2000-2010			2010-2020			2020-2025		
		FAO1	FAO2	FAO3	FAO1	FAO2	FAO3	FAO1	FAO2	FAO3	FAO1	FAO2	FAO3
CSC	World	1.1	0.9	0.7	-0.8	-1.5	-3.0	-1.4	-1.9	-2.9	-0.8	-1.1	-1.8
	AI	-2.4	-2.7	-3.4	-2.5	-3.1	-4.2	-2.1	-2.4	-3.3	-1.7	-1.9	-2.5
	NAI	3.5	3.5	4.1	1.7	1.6	1.2	0.9	0.8	0.6	0.9	0.8	0.6
NFC	World	5.2	5.7	7.1	3.2	3.5	4.3	2.9	3.2	4.0	2.8	3.2	3.8
	AI	0.3	0.5	0.6	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.4
	NAI	4.9	5.2	6.5	3.1	3.4	4.1	2.8	3.0	3.3	2.7	2.9	3.5
FL	World	-4.0	-4.8	-6.3	-3.9	-4.9	-7.1	-4.1	-4.7	-6.6	-3.6	-4.2	-5.7
	AI	-2.7	-3.1	-4.0	-2.6	-3.3	-4.5	-2.3	-2.6	-3.6	-1.8	-2.2	-2.9
	NAI	-1.4	-1.7	-2.4	-1.4	-1.8	-2.9	-1.9	-2.4	-3.1	-1.8	-2.1	-2.8

3.1.2 Comparisons to UNFCCC data

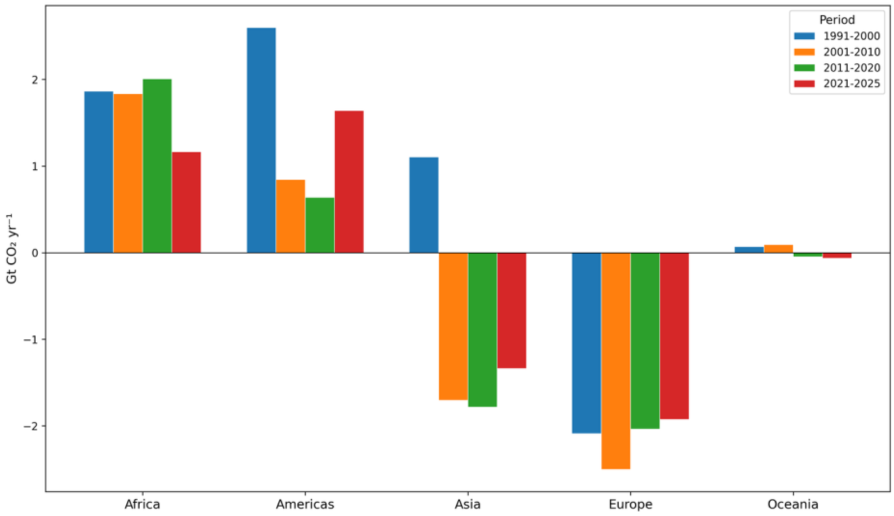
We compared FAO *NFC* and *FL* results to the UNFCCC data collected and re-disseminated within the same dataset presented in this work. In order to provide a consistent basis for comparison, we re-computed World, AI and NAI aggregates limited to countries present in the UNFCCC dataset. We performed such comparisons over the entire time series 1990-2025 (Fig. 3a-c), as well as in terms of long-term 2001-202~~1~~3 averages (Tab. 5), consistently with recent analyses (Grassi et al., 2022; Melo et al., 2025)~~ and)~~. Results of both timeseries comparison and long-term averages indicated good agreement of FAO estimates and UNFCCC data—with the range of FAO models consistently including the corresponding UNFCCC values—across all items (NFC, FL) and group (World, AI, NAI) combinations, except for *FL* fluxes for the NAI aggregate. Within the underlying 50% uncertainties making all results presented herein not statistically different, our results highlighted, at least qualitatively, a 'sink gap' in NAI countries, i.e., stronger forest removals in UNFCCC data vs FAO estimates ranging between 1.2 - 2.4 Gt CO_2 yr^{-1} across FAO estimates—with the smaller gap corresponding to FAO 3 model estimates (Tab. 5). As discussed in more detail in the next section, this gap coincided almost entirely with the FAO/UNFCCC difference arising from the set of countries reporting zero carbon stock change densities to FAO via the FRA.

Figure 3a. World total net forest emissions/removals estimates, 1990-2025 for three FAO stock change models and global coverage, UNFCCC and FAO LMTD aggregates limited to UNFCCC reporting countries. Shaded areas represent 50% uncertainty (95% CI) around the intermediate FAO 2 model.



~~Figure 3. Annual net forest emissions/removals by FAO regions in the period 1990-2025.~~

Figure 3b. AI aggregates of net forest emissions/removals estimates, 1990-2025 for three FAO stock change models and global coverage. UNFCCC and FAO LMTD aggregates limited to UNFCCC reporting countries. Shaded areas represent 50% ~~uncertainty (95% CI) around the intermediate~~ FAO 2 model.



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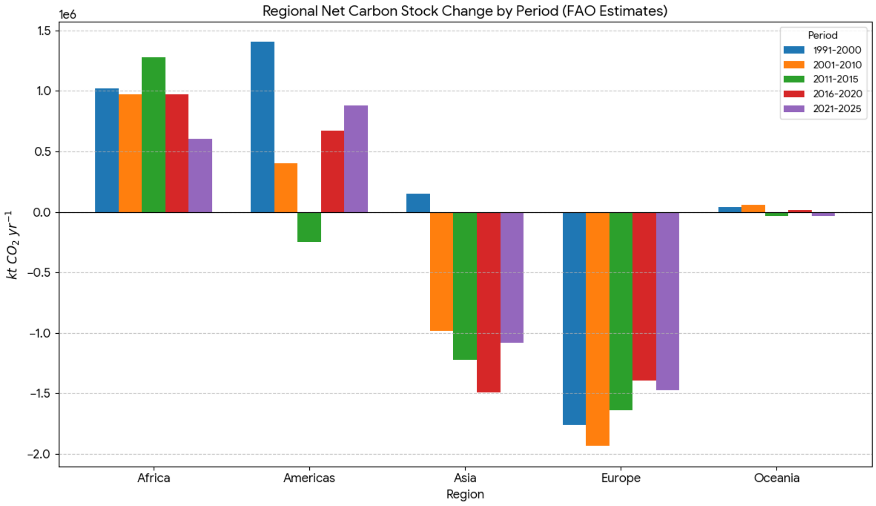

~~Figure 3. Annual net forest emissions/removals by FAO regions in the period 1990-2025FAO regional net forest emissions/removals (REF to the data here).~~.

~~3.2 Emissions from net forest conversion~~

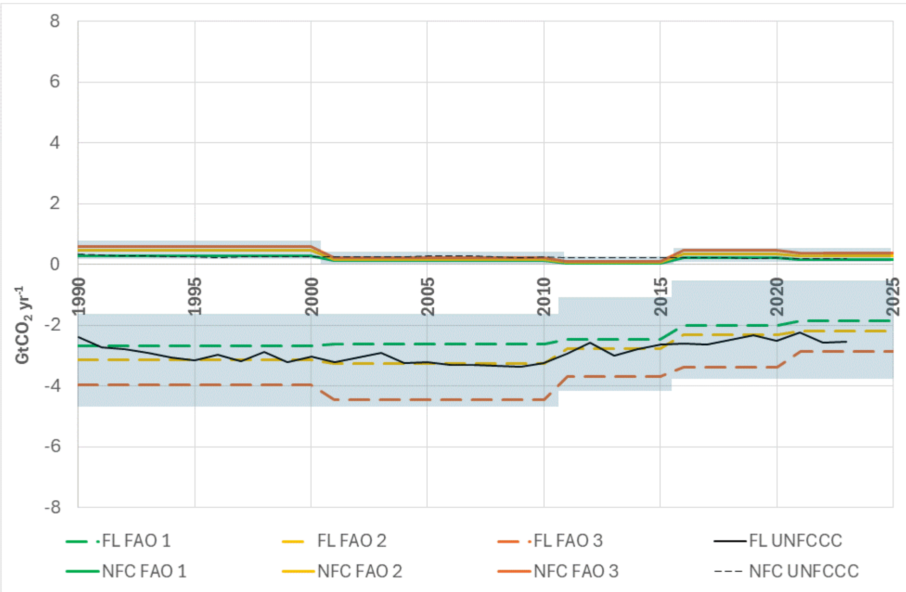

Figure 3c. NAI aggregates of net forest emissions/removals estimates, 1990-2025 for three FAO stock change models and global coverage. UNFCCC and FAO LMTD aggregates limited to UNFCCC reporting countries. Shaded areas represent 50% uncertainty (95% CI) around the intermediate FAO 2 model.

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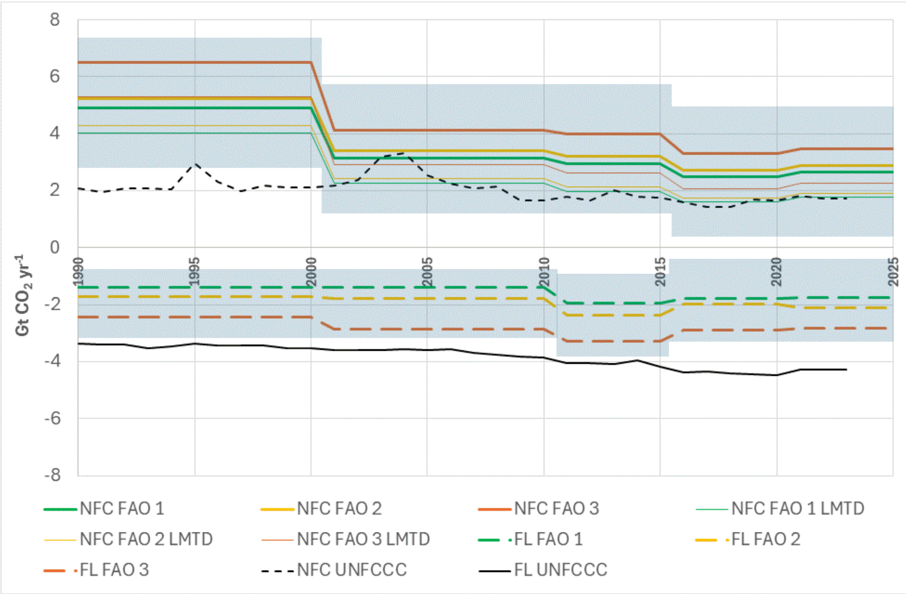

Table 5. Comparison of FAO net forest emission/removal estimates and UNFCCC country data, by world, Annex I (AI) and non-Annex I (NAI) aggregate groups, 2001-2023 averages (Gt CO_2 yr^{-1}). The column n (%) indicates the number of countries included in the analysis based on UNFCCC reporting, and their percentage coverage with respect to full geographic coverage. FAO estimates show three carbon stock change models.

Item	Group	n (%)	FAO 1	FAO 2	FAO 3	UNFCCC
	World	81 (42%)	2.1	2.3	2.8	2.2
NFC	AI	42 (100%)	0.1	0.2	0.3	0.2
	NAI	39 (25%)	2.0	2.2	2.6	2.0
	World	134 (69%)	-3.9	-4.7	-6.7	-6.9
FL	AI	42 (100%)	-2.3	-2.8	-3.9	-2.9
	NAI	92 (60%)	-1.6	-1.9	-2.8	-4.0

~~The FAO estimates indicated that world total emissions from net forest area loss decreased significantly over time, halving decreasing significantly from their 1990 levels of nearly 76 Gt CO_2 yr^{-1} to about 3nearly 4 Gt CO_2 yr^{-1} in 2025 (Fig. 2). This trend was almost entirely driven by NAI countries, which represented consistently more thanabout 90% of the world total emissions. Regionally, the global trend was principally driven by strong reductions of roughly 1.5 Gt CO_2 yr^{-1} both in the Americas (from 3.93 to 2.41 Gt CO_2 yr^{-1}) and Asia (from 1.72 to 0.43 Gt CO_2 yr^{-1}). Africa contributed to about 1.4 Gt CO_2 yr^{-1} to the world total up to 2010, decreasing to 10.8 Gt CO_2 yr^{-1} in 2025 (Fig. 3). Europe and Oceania were minor relative contributors to world totals and trends. In terms of climate zones, nearly all of the global emissions from net forest conversion were concentrated in the tropics. Accounting for litter and dead wood and soil carbon pools added about 3710% to global emissions compared to including living biomass only (FAO, 2025b).~~

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~~In the end, the above global and regional trends in net forest conversion emissions were driven by loss of high biomass density naturally generating forest in a relatively small number of countries (Tab. 6). With respect to the last decade covered by the FRA 2025, 2016-2025, Brazil alone (1,200 356 Mt CO_2 yr^{-1}) represented nearly 40%over a third of the world total of 3.81 Gt CO_2 yr^{-1}, while four countries represented more than 50% of the world total, including with Brazil, the Democratic Republic of the Congo (DRC) (235170 Mt CO_2 yr^{-1}), Canada (163 199Mt CO_2 yr^{-1}) and Peru (13510 Mt CO_2 yr^{-1}). The top ten countries represented 657% of the world total. Of these, half had not reported data to UNFCCC, specifically the Democratic Republic of the Congo (DRC), Peru, Cameroon, Colombia, and Tanzania, amounting together to nearly 500 Mt CO_2 yr^{-1}.~~

~~**3.3 Emissions/removals on forest land**~~

~~The FAO estimates showed that forests acted consistently as strong carbon sinks on remaining forest land over time, sequestering betweenwell aboveabout (in absolute terms) -6 toand 74 Gt CO_2 yr^{-1} over the period considered, albeit with indications of a weakening strength since 2010, though not statistically significant (Fig. 2). Data for the AI and NAI country aggregates showed opposite trends with the sink in forest land decreasing for the former, by about 1 Gt CO_2 yr^{-1} from 1990 to 2024, whereas the latter exhibited a small sink increase, to become an equal contributor by 2020-2024. Regions were consistent sinks over the study period, except for Africa. Europe, Asia and the Americas all acted as large sinks, with Europe the strongest (nearly -2 Gt CO_2 yr^{-1} in early decades peaking at -2.7 Gt CO_2 yr^{-1}, then , decreasing to about -2 Gt CO_2 yr^{-1} after 2010). Nonetheless, while removals on FL decreased from 1990 to 2025 by about 15% in Europe and by nearly 40% in the Americas, they increased by 30% in Asia. By comparison, Africa and Oceania had small fluxes on forest land (Fig. 3).~~

3.23 ~~Emissions/removals on forest land~~Country results

Country-level analyses were carried out over the same long-term 2001-2023 average used above. Results underscored that global and regional trends were driven by a relatively small number of countries, typically no more than 10-15, most of them countries with large forest areas. Specifically, both FAO and UNFCCC data suggested that world total *NFC* emissions were driven by just two countries, Brazil and the Democratic Republic of Congo (DRC), which were responsible for roughly 70% of the world total, with the top ten countries covering about 90% (Tab. 6).

Table 6. Top ten net forest conversion fluxes, 2001-2023 averages (Gt CO_2 yr^{-1}). Ordered by UNFCCC values.

Country	FAO 1	FAO 2	FAO 3	UNFCCC
Brazil	1.2	1.3	1.5	0.97
DRC	0.34	0.36	0.50	0.57
Indonesia	0.03	0.03	0.05	0.16
USA	0.02	0.03	0.05	0.10
Côte d'Ivoire	0.05	0.05	0.05	0.06
Australia	0.03	0.04	0.05	0.05
Argentina	0.09	0.10	0.12	0.05
Paraguay	0.06	0.06	0.09	0.03
Ecuador	0.03	0.03	0.04	0.02
Malaysia	0.03	0.03	0.05	0.02

Furthermore, the range provided by the three FAO carbon stock change models was consistent with UNFCCC data for Brazil, Cote d'Ivoire, Australia and Ecuador. Conversely FAO estimates were smaller than UNFCCC for DRC, Indonesia and United States of America (USA), while they were larger for Argentina, Paraguay and Malaysia. Additionally, the FAO dataset included several countries that either had UNFCCC data but did not appear within the UNFCCC top ten (Fig. 4), such as Canada (0.06 – 0.15 Gt CO_2 yr^{-1}), or did not appear in the UNFCCC dataset collected for this work, such as Peru (0.1 – 0.2 Gt CO_2 yr^{-1}), Myanmar (0.07 – 0.09 Gt CO_2 yr^{-1}), Colombia (0.08 – 0.09 Gt CO_2 yr^{-1}), Tanzania (0.05 – 0.08 Gt CO_2 yr^{-1}), Bolivia (0.06 – 0.08 Gt CO_2 yr^{-1}) and Cameroon (0.05 – 0.06 Gt CO_2 yr^{-1}).

~~Finally, with respect to climate zones, boreal forests and temperate zone forests contributed each to the global removals by about -1 Gt CO2 yr-1 in 2020-2024, with the remainder evenly split between tropical and semi-tropical forest biomes.~~With regards to *FL* fluxes, both FAO and UNFCCC data showed that just ~~As noted in the case of NFC, global and regional trends in FL were driven by a small number of countries (Tab. 7).~~ three countries, Russian Federation, USA and China, were responsible for 40-60% of world total net forest removals, with the top ten countries summing up to 70-80% (Tab. 7). Within the top ten countries, FAO estimates were consistent with UNFCCC data for the Russian Federation, USA, and China~~ and Brazil~~. They were substantially smaller than UNFCCC for DRC, Mali, Venezuela, Malaysia and Mexico, and substantially larger for Brazil. The drivers of these country-level discrepancies are further investigated in the Discussion. Finally, the FAO estimates identified important forest sink countries that did not appear within the UNFCCC top ten (Fig. 4), such as Canada (+0.06 – -0.2 Gt CO_2 yr^{-1}), India (- 0.1 – 0.2 Gt CO_2 yr^{-1}), Belarus (- 0.06 – 0.1 Gt CO_2 yr^{-1}), France (- 0.05 – 0.09 Gt CO_2 yr^{-1}) and Vietnam (- 0.05 – 0.07 Gt CO_2 yr^{-1}).~~With respect to 2016-2024, two countries, Russia (-1,120 Mt CO2 yr-1) and China (-1,026 Mt CO2 yr-1) represented 50% of the world total of 4.3 Gt CO2 yr-1.~~

Table 7. Top ten removals on forest land, 2001-2023 averages (Gt CO_2 yr^{-1}). Ordered by UNFCCC values.

Country	FAO 1	FAO 2	FAO 3	UNFCCC
Russia	-1.1	-1.2	-1.5	-1.3
USA	-0.8	-0.9	-1.1	-0.9
China	-0.6	-0.8	-1.3	-0.7
DRC	0.0	-0.0	-0.0	-0.3
Mali	0.0	0.0	0.0	-0.3
Brazil	-0.5	-0.5	-0.6	-0.3
Venezuela	0.0	-0.0	-0.0	-0.3
Indonesia	-0.1	-0.1	-0.3	-0.3
Malaysia	-0.0	-0.0	-0.1	-0.2
Mexico	-0.0	-0.1	-0.1	-0.2

Figure 4. Comparison of FAO and UNFCCC country data for top 10 *NFC* emissions and *FL* removals, 2001-2023 averages.

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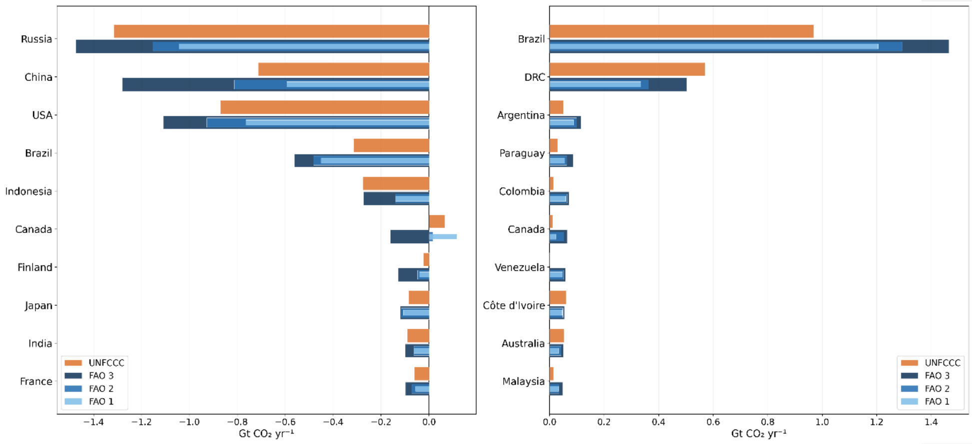

4. Discussion

~~Argentina~~	~~115~~	~~50~~	~~65~~
~~Venezuela (Bolivarian Republic of)~~	~~58~~	~~0~~	~~58~~
~~Colombia~~	~~72~~	~~14~~	~~57~~
~~Paraguay~~	~~86~~	~~29~~	~~56~~
~~Canada~~	~~64~~	~~12~~	~~53~~
~~Finland~~	~~42~~	~~4~~	~~38~~
~~Malaysia~~	~~49~~	~~15~~	~~34~~
~~United States of America~~	~~46~~	~~104~~	~~-58~~
~~Democratic Republic of the Congo~~	~~502~~	~~569~~	~~-67~~
~~Indonesia~~	~~46~~	~~164~~	~~-118~~

Notwithstanding the uncertainty considerations highlighted earlier, we performed additional country-level analyses to better characterize the 'sink gap' identified earlier between the FAO and UNFCCC data on forest

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removals in NAI countries, amounting to roughly 1 Gt CO_2 yr^{-1} when using FAO 3 estimates (see Tab. 5). Extending the country-level discrepancies identified in Tab. 7, our analysis showed that this aggregate NAI gap was driven by 13 countries (Tab. 8), concentrated in tropical Africa (Mali, DRC, Madagascar, Cameroon, Gabon and Namibia), Latin America and the Caribbean (Venezuela, Guyana and Mexico) and Southeast Asia (Malaysia), collectively generating a cumulative sink gap of about 2 Gt CO_2 yr^{-1} ~~Our data showed that, similarly to earlier findings, this aggregate NAI gap was driven by a handful of countries, specifically, Mali, the Democratic Republic of Congo, Madagascar, Cameroon, Gabon and Namibia in Africa; Venezuela, Guyana and Mexico in Latin America and the Caribbean; and Malaysia in Southeast Asia, collectively generating a cumulative sink gap of about 2 Gt CO_2 yr^{-1}~~ (Tab. 8). This was diminished by a cumulative source gap of about 1 Gt CO_2 yr^{-1} generated in three additional countries, Brazil, Nigeria and China, for which FAO removals were larger than UNFCCC, with the balance fully explaining the noted NAI FAO/UNFCCC discrepancy. Remarkably, the ‘outlier’ countries in Tab. 8 were virtually the same identified in recent similar comparisons developed in the context of the LULUCF data hub (Melo et al., 2025). This suggested that this list of countries was likely not random, making it sensible to investigate reasons for the observed discrepancy. While this is a topic deserving its own independent effort, we note that certain typologies could be readily identified, building on previous work (Grassi et al., 2022; Melo et al., 2025). For instance, our analysis showed that all of the six outlier countries in tropical Africa, corresponding to a UNFCC/FAO sink gap of 1 Gt CO_2 yr^{-1}, had conversely zero carbon stock density change in the FRA. Thus a first typology identified here was a potential data quality gap that could be further addressed by FAO through dedicated statistical capacity development programs, aimed at improving alignment between FAO and UNFCCC activity data. At the same time, Melo et al. (2025) suggested that the forest sinks in these same countries were ‘not credible,’ considering that current evidence rather suggested forest degradation due to human intervention.

Table 8. Comparison of FAO and UNFCCC net emissions/removals on forest land (2001-2023 average), showing top differences for countries with removals greater than 0.1 Gt CO_2 yr^{-1}. FAO 3 results used for simplicity.

Country	FAO	UNFCCC	DIFF
Mali[a]	-0.0	-0.3	+0.3
DRC[a]	-0.0	-0.3	+0.3
Venezuela	-0.0	-0.3	+0.3
Malaysia	-0.1	-0.2	+0.2
Madagascar[a]	+0.0	-0.1	+0.2
Guyana[a]	+0.0	-0.2	+0.2
Mexico	-0.1	-0.2	+0.1
Cameroon[a]	-0.0	-0.1	+0.1
Gabon[a]	-0.0	-0.1	+0.1
Namibia[a]	+0.0	-0.1	+0.1
Brazil	-0.6	-0.3	-0.3
Nigeria[a]	-0.0	+0.3	-0.3
China	-1.3	-0.7	-0.6

[a] Constant carbon stock density data in FRA

A second typology of discrepancy was related to land use boundary issues, specifically concerning UNFCCC country-reported managed forest areas that were larger than the corresponding FAO total forest land area (see also methods). Namibia exemplified such case perhaps in the extreme. In this country, accounting for forest carbon sinks on woody savannah encroachments areas (Stevens et al., 2017; IPCC, 2022), leading to a UNFCCC forest

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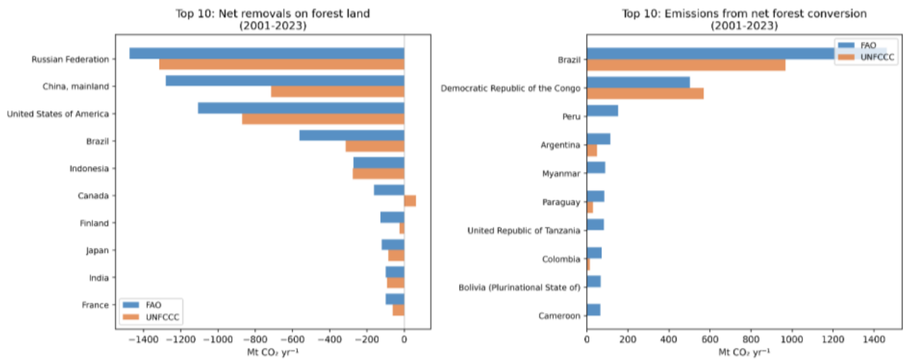
area nearly 10 times larger than the FAO forest land area (see methods), was likely the underlying reason for the observed UNFCCC/FAO gap at country level. A third discrepancy also related to land use boundary issues, but in the opposite direction, i.e., concerning UNFCCC country-reported managed forest areas smaller than the corresponding FAO total forest land—a case much discussed in the literature (Grassi e-t al., 2022). We showed earlier (see methods) that available UNFCCC and FRA statistics indicate that only a few large countries fit this typology. Among these, Brazil was perhaps the most extreme, reporting to UNFCCC managed land areas that were about 60% smaller than the FAO forest land area. We found that proportionally adjusting the FAO removal estimates by this proportion was sufficient to align FAO and UNFCCC removals.

These typologies could be used to guide dedicated statistical programs in countries as discussed. At the same time, the fact that the discrepancies between FAO and UNFCCC data were concentrated in a handful of countries suggested that the underlying forest activity data were already aligned for most other countries.



~~4.2.2 Forest Land~~

~~Limited to the 94 134 countries reporting to the Convention for the period 2016-20252001-2023,~~ With the above increased understanding, which pointed to specific country differences within an overall credible global assessment, we further tested the FAO global forest net emissions/removals estimates against the most recent Global Carbon Budget (GCB) data, including forest-related bookkeeping and dynamic global vegetation model output, JRC NGHGI data, and atmospheric inversions (Friedlingstein et al., 2026). To this end we used FAO 3 estimates as the most relevant in the context of global land carbon cycle assessments. Results showed that the FAO estimates for both *NFC* and *FL* fluxes were in very close agreement with the independent estimates published within the GCB (Fig. 5), the latter indicating world total deforestation emissions of~~ed~~ roughly 4 Gt CO_2 yr^{-1}, counterbalanced by forest removals of 6-7 Gt CO_2 yr^{-1}. The resulting FAO estimates of net carbon stock change in forest, about -2 Gt CO_2 yr^{-1} were additionally consistent with the average results of fourteen atmospheric inversion models.~~the FAO~~

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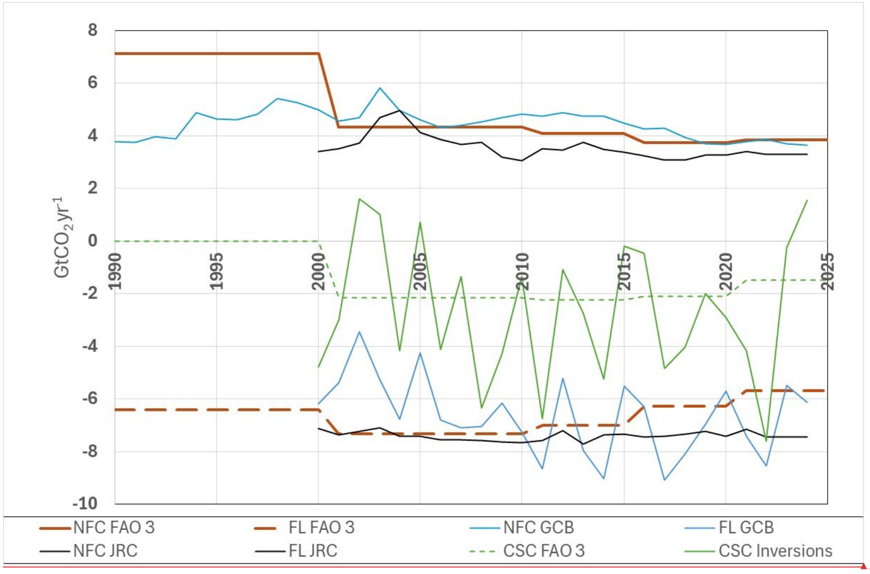
Figure 5. Comparison of FAO 3 full carbon stock change estimates to datasets published in GCB (Friedlingstein et al., 2025): JRC: gap-filled NGHGI data; GCB: Bookkeeping models for NFC and adjusted DGVMs for FL; Inversions: net land carbon stock change from atmospheric inversions.



The country analysis and the global agreement shown above helped to confirm the positive role that FAO data can play alongside other established approaches, to help build confidence in the robustness of national, regional and global net forest emissions/removals assessments, while demonstrating the consistency of the underlying national data sources. ~~dt~~

We nonetheless feel compelled to close this discussion by highlighting that the large ±50% uncertainty (95% CI) underlying the emissions/removal estimates discussed herein made most country estimates produced across FAO, UNFCCC and GCB models, statistically indistinguishable. The valuable qualitative insights discussed were nonetheless useful to highlight areas of improvement in FAO and UNFCCC data collection efforts aimed at ensuring better alignment and comparability.

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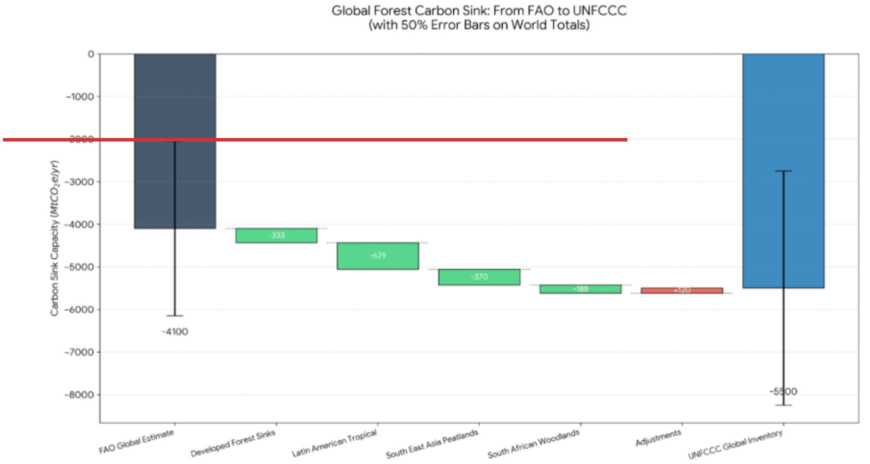

5. Conclusions~~s~~

~~to improve comparability and support climate-policy implementation~~We provided a detailed analysis based on the most recent FRA 2025 data to show that the FAO net forest emissions and removals dataset 1990-2025 continue to represent a useful benchmarking tool in support of country reporting processes and a solid contributor to global assessments. First, we showed that land use boundary issues, while conceptually important in distinguishing FAO and UNFCCC data, were less important than suggested in current literature. We found that in practice, most countries reported managed forest areas to UNFCCC that were larger or equal to, not smaller than, total forest land area reported to FAO. Hence flux estimates made on the entire forest land area could be considered anthropogenic in the sense of the IPCC land use proxy, increasing comparability of FAO and UNFCCC reporting. Secondly, we found a substantial agreement of the new FAO estimates with recent Global Carbon Budget data, following inclusion of all relevant carbon pools in the FAO calculations. Finally, we argued that while the knowledge gained through the comparison of multiple independent approaches was extremely useful in highlighting areas of agreement and disagreement and therefore in providing insight into needed future work to improve national, regional and global assessments, the large uncertainties underlying FAO, NGHGI and GCB data need to be acknowledged in country data comparisons. We nonetheless strongly support the recommendations that are emerging in the current literature towards the development of internationally coordinated capacity development programs, contributed by relevant actors in collaboration with countries, as recently outlined by the LULUCF data hub consortium. To this end, we underline that FAO is uniquely positioned to contribute to such efforts, as the UN agency with the official mandate to collect and disseminate forest and land use statistics from its member countries. Our ultimate goal was and remains to improve the quality and comparability of country data submitted to relevant international processes in support of improved evidence-based decision making on climate change and forests.~~.~~

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Authors' contributions. FT led the development and analysis of the FAOSTAT data. AP and AB provided the FRA 2025 data and contributed to data analysis. GO, NR, MP, NW, RB, RDC and ~~and~~ GC contributed data analysis and helped develop the FAOSTAT database.

Competing interests. Author Francesco N. Tubiello is a member of the editorial board of the journal.

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Data Availability. Full dataset is available on Zenodo (Tubiello and Obli-Laryea ~~et al.~~, 2026~~5~~) at: 10.5281/zenodo.20085666~~10.5281/zenodo.17395879~~.

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