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New estimates of CO_2 forest emissions and removals: 1990–2015 ☆

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ABSTRACT

Using newly available data from the 2015 Forest Resources Assessment (FRA), we refined the information, currently available through the IPCC AR5 and FAOSTAT, on recent trends in global and regional net CO_2 emissions and removals from forest land, including from net forest conversion (used as a proxy for deforestation) and forest remaining forest. The new analysis is based on the simplified forest carbon stock method of the FAOSTAT Emissions database, equivalent to a Tier 1, Approach 1 IPCC methodology, limited to biomass carbon stocks. Our results indicated that CO_2 emissions from net forest conversion decreased significantly, from an average of 4.0 Gt CO_2 yr^{-1} during 2001–2010 to 2.9 Gt CO_2 yr^{-1} during 2011–2015. More than half of the estimated reductions over the last five years, some 0.6 Gt CO_2 yr^{-1}, took place in Brazil. Detailed analyses further indicated that remaining forests continued to function as a net carbon sink globally, with an average net removal of −2.2 Gt CO_2 yr^{-1} during 2001–2010, and −2.1 Gt CO_2 yr^{-1} during 2011–2015. Annex I Parties represented the bulk of this sink, contributing 60% of the total in 2011–2015, down from 65% in 2001–2010. Compared to previous FAOSTAT assessments for the period 2001–2010, based on the 2010 FRA and published in the IPCC AR5, the use of FRA 2015 data led to estimates of net forest conversion that were consistent with previous ones (4.0 vs. 3.8 Gt CO_2 yr^{-1}), while the estimated forest sinks were 22% larger (−2.2 vs. −1.8 Gt CO_2 yr^{-1}). The net contribution of forests to anthropogenic forcing based on FRA2015 data was thus smaller than previously estimated by the IPCC AR5. Finally, we separated for the first time net emissions and removals from forest land into a sink component and a degradation component. Results indicated that, contrary to CO_2 emissions from deforestation, CO_2 emissions from forest degradation increased significantly, from 0.4 Gt CO_2 yr^{-1} in the 1990s, to 1.1 Gt CO_2 yr^{-1} in 2001–2010 and 1.0 Gt CO_2 yr^{-1} in 2011–2015. Emissions from forest degradation were thus one-fourth of those from deforestation in 2001–2010, increasing to one-third in 2011–2015.

1. Introduction

The Food and Agriculture Organization of the United Nations (FAO) makes available online data on forests, originally submitted by its Member States and analyzed through the Global Forest Resource Assessment (FRA) (MacDicken, 2015). FRA data, available over the period 1990–2015, include, among others, estimates of forest area and of carbon stocks in aboveground and belowground biomass carbon pools. The latter data categories are needed in standard carbon cycle computations of forest dynamics, in line with methods provided in the 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006). Since 2012, FAO has used FRA data to estimate net CO_2 emissions and removals associated with C stock changes of the biomass C pools, related to forest land and net forest conversion, the latter used as a proxy for net deforestation (FAOSTAT, 2015; FAO, 2014). The FAO data, considered equivalent to a Tier 1, approach 1 estimate using the carbon stock difference method of the IPCC guidelines, were published in the IPCC AR5 (Smith et al., 2014).

The FRA is the only global database that provides the value and historical trend of C stock changes in forest for each country, using official data provided by countries to FAO. An additional repository of data on forest carbon dynamic is the database of the UN Framework Convention on Climate Change (UNFCCC), which contains data submitted by its Parties (http://unfccc.int/national_reports/items/1408.php).

There are important differences between the FRA and UNFCCC. First, the UNFCCC database currently does not cover all UN

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Member States. In coming years, new country submissions of Biennial Update Reports[1] to UNFCCC by non-Annex I Parties[2] will increase coverage, while adding valuable information on management practices, area, carbon stocks and their changes.

Second, even though UNFCCC requires its Parties to provide data on forest land that are consistent with those they submit to FAO[3], often the data provided to FAO are numerically different from those submitted to UNFCCC, stemming from discrepancies in forest definitions applied[4], and from the fact that different national focal points are responsible for FAO and UNFCCC submissions.

The FAOSTAT Emissions database is one of three independent sources used in the recent IPCC Fifth Assessment Report (AR5) to estimate anthropogenic GHG emissions and removals from Agriculture, Forestry and Other Land Uses (AFOLU) (Tubiello et al., 2015). In particular, for CO_2 emissions and removals from forest, FAOSTAT provided estimates of net forest carbon stock change at national, regional and global levels to the IPCC AR5. Using data from the FRA 2010 (FAO, 2010), and with reference to the period 2001–2010, FAO estimated average decadal CO_2 emissions from deforestation of 3.8 Gt CO_2eq yr^{-1} and a net carbon sink in forest land of −1.8 Gt CO_2eq yr^{-1}. Additional GHG emissions from terrestrial C pools estimated by FAO to the IPCC AR5, but not discussed herein, included emissions from drained peatlands (0.9 Gt CO_2eq yr^{-1}) and from biomass fires (0.3 Gt CO_2eq yr^{-1}).

This paper provides FAOSTAT updates of CO_2 emissions and removals from forests, based on FRA 2015 data. Furthermore, this paper introduces an improved methodology to assess separately, within the forest domain, net CO_2 emissions from forest degradation and net CO_2 removals from forest re-growth, thus providing for the first time in the literature, an assessment of both of these important terrestrial carbon fluxes.

2. Materials and methods

FAOSTAT estimates of CO_2 emissions and removals from forest were computed following the carbon stock difference equation of the 2006 IPCC Guidelines, using FRA country information on forest area and carbon stock density[5] as input. This was considered equivalent to an IPCC Tier 1, approach 1 method (FAO, 2014). In fact, the stock difference method is not the IPCC default[6], because its application requires the use of statistically consistent time-series of national forest inventory data, which are not typically available in all countries. The FRA however provides exactly this type of information, including forest area activity data and carbon stock-change factors by country, making the application of stock difference equations within FAOSTAT much simpler than the gain-loss method. More specifically, we used FRA data for the years 1990, 2000, 2005, 2010, and 2015, including total national *forest area*, *A*, and its three subcategories: *primary forest*, *other naturally regenerated forest*, and *planted forest*; as well as total *woody biomass carbon stock*, *B* (defined as above and below-ground biomass)[7]. FRA data also included some information on carbon stocks in litter, deadwood and soils. Coverage by country was rather incomplete however, so that this information was not used herein.

FRA 2015 data presented country data gaps on forest area by subcategory, especially for the first two mentioned above, and on woody biomass. These data gaps were filled as follows. For forest area, missing total forest area data were linearly extrapolated or interpolated using existing FRA data, as needed. When the proportion of forest area among sub-categories was missing we used information on shares by forest subcategory from neighboring countries with similar forest conditions, and applied these shares to total forest area. For total woody biomass, we used the relevant sub-regional weighted average value[8], and multiplied it by the total country forest area.

All data were linearly interpolated to obtain a yearly time series over the period 1990–2015. As described below in more detail, annual data were used as input to compute net CO_2 emissions and removals on *forest*, including forest land area (hereafter referred to as *forest land*) and forest area converted to other land uses (hereafter referred to as *net forest conversion or deforestation*). The terminology used herein is in line with the relevant database categories of the FAOSTAT Emissions database—Land use (http://faostat3.fao.org/browse/G2/*/E). It may be considered consistent with REDD+, albeit representing an over-simplification of current GHG national reporting practice[9].

2.1. Derived input data

Annual data needed as input into the FAOSTAT stock difference methodology were derived from FRA2015, by country and over the period 1990–2015, including:

- *Forest area*, $A_i(t)$. Total forest area A, disaggregated into two forest strata *i* as follows:
  - *Natural forest area*, defined as the sum of FRA area data for sub-categories *primary forest* and *other naturally regenerating* forest; and
  - *Planted forest area,* taken directly from the FRA.

The above aggregation of *natural forest* was made to ensure that net area losses of primary to secondary forest, a typical outcome of forest resources exploitation, would not be counted as forest area change. Thus the associated carbon losses were counted as forest degradation rather than deforestation. At the same time, separating this stratum from *planted forest* was necessary in order to identify areas and associated CO_2 emissions from deforestation of *natural forest*, separately from those associated to afforestation with plantations.

- *Woody biomass carbon stock density*, *b*. Computed as *B*/*A*, where *B* was the FRA national total woody biomass carbon stock and *A* the total national forest area. FRA biomass data were provided

[1] Biennial Update Reports contain, among other information, a GHG Inventory for forest land, and an annex on the implementation of REDD+ activities: forest conservation, sustainable forest management, enhancement of carbon stocks, reducing emissions from deforestation and forest degradation.

[2] Annex I Parties include the 24 original OECD members, the European Union, and 14 countries with economies in transition. While non-Annex I Parties have currently no legal commitment to reducing their greenhouse-gas (GHG) emissions, Annex I Parties committed to returning their GHG emissions to 1990 levels by the year 2000, under UNFCCC Article 4.2 (a) and (b), and accepted emissions targets for the period 2008–12 under Article 3 and Annex B of the Kyoto Protocol.

[3] UNFCCC decision 16/CMP1, para16; 2/CMP8 Annex I para1f; 12/CP7 Annex, para n.

[4] FAO member countries must report to FRA using the FAO forest definition (i.e., minimum area 0.5 ha, minimum cover 10%, minimum height 5 m), while they can report to UNFCCC using their national forest definitions, which may differ from FAO's. Furthermore, reported FRA data cover the entire national forest area, as they must include unmanaged forest land. By contrast, UNFCCC submissions may be limited to managed forest land.

[5] Defined as carbon stock per hectare of total biomass (above-and below-ground).

[6] The IPCC default method is the "gain-loss" method, requiring information on net forest growth rates, harvest data and estimated losses from disturbances.

[7] FRA data by country are available at http://www.fao.org/forestry/fra/67090/en/.

[8] FAO sub-regions and number of countries (in parenthesis) with no national value in FRA: Eastern Africa (1), Western Africa (2), North America (2), Central America (1), Caribbean (13), South America (3), South-Eastern Asia (3), Western Asia (6), Northern Europe (3), Southern Europe (1), Australia and New Zealand (1), Melanesia (2), Micronesia (1), Polynesia (5).

[9] In GHG national inventories, net emissions associated with deforestation are reported in the new land category to which forest was converted. By contrast, assessing net emissions and removals from *deforestation* and from *forest land* separately, as well as reporting their sum as net emissions and removals from *forest*, is relevant to REDD+.