GHG fluxes from forests: An assessment of national reporting and independent science in the context of the Paris Agreement

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Policymaker Summary

The Paris Agreement suggests several ambitious global mitigation goals: to hold the increase in global average temperature to well below 2°C (pursuing 1.5°C), to reach global peaking of greenhouse gas (GHG) emissions as soon as possible, and achieve a balance between anthropogenic emissions and removals in the second half of this century. These goals require a significant contribution from forests—not only through reducing deforestation in the tropics, but also by increasing the global sink capacity of forests.

Objectives of the study

Assessing the contribution of forests to global mitigation efforts requires understanding of both *national* GHG inventories (GHGIs), on which Nationally Determined Contributions (NDCs) are based, and results from independent scientific studies focused on *global* estimates of fluxes from forests. The data, information and methodologies used by national governments to report emissions and removals may differ from that used in independent scientific studies. This assessment seeks to:

a) Clarify what forest-related emissions and removals are (and are not) included in national GHGIs;

b) Compare national reporting to independent scientific studies, and provide an explanation of why and how they differ;

c) Provide recommendations on how additional transparency could improve understanding of the forest contribution to the global carbon budget.

The study is considered a first step in better understanding differences in estimates of forest-related GHG fluxes, to provide a basis for considerations of improvements in country-level reporting and global scale assessments—as both provide critical information towards delivering on Paris Agreement goals.

Coverage of GHG fluxes in national GHG inventory reporting on forests

National GHGI reporting under the United Nations Framework Convention on Climate Change (UNFCCC) aims to provide information to assess the overall effects of measures taken by each Party and the cumulative impacts (UNFCCC Article 7). The Paris Agreement also created a transparency framework (Article 13) that includes national GHGIs, with the objective of building mutual trust and confidence and to provide a clear understanding of climate change action. National GHGIs will be critical for providing transparency on progress toward achieving NDCs and to inform global stocktaking efforts.

National GHGIs contain *anthropogenic* emissions and removals and are used to quantify the mitigation efforts of each country. Non-anthropogenic emissions and removals are not included in national GHGIs, and to do so would complicate the assessment of net emission reductions achieved by mitigation actions.

The managed land proxy: IPCC Guidelines for national GHGIs apply a concept called the *managed land proxy* as a first order separation of anthropogenic and non-anthropogenic emissions and removals. The rationale for this approach is that the preponderance of anthropogenic effects occurs on managed lands. This proxy has been introduced to overcome the challenge of separating human-induced from natural effects, absent practicable methodologies to do so. Areas of land considered "managed" are defined by national governments, and should follow IPCC guidance which states that managed land is *land where human interventions and practices have been applied to perform production, ecological or social functions*. Consequently, GHGIs do not include estimates of GHG fluxes from areas that are designated as "unmanaged." Specific emissions and removals that would be excluded from a GHGI, to the extent they occur on unmanaged land, include:

a) carbon sinks, with the most significant fluxes due to accumulation of carbon in dead organic matter (e.g. black carbon from fire, organic matter in peat soil), regrowth after disturbances, forest expansion on unmanaged lands because of treeline shifts due to climate change, and fertilization effects due to increased atmospheric CO_2 or atmospheric N deposition;

b) emission sources, including wildfires and other disturbances (such pest outbreaks), mortality caused by climate change and associated impacts on peat lands from permafrost thaw.

These emissions and removals can be potentially significant, and may explain some of the apparent disparities between GHGI reporting to the UNFCCC and independent scientific studies.

Capacity for reporting: Generally speaking, all 43 Annex I (developed) countries have well-established national systems that employ technical experts and researchers within government departments or agencies. Such countries have submitted, to date, national GHGI reports annually from 2003 to 2016 (i.e. 14 per country, covering the period since 1990), National Communications every four years (i.e. six from each country), and two biennial reports (i.e. in 2014 and 2016, or two per country). All such reports are reviewed by technical experts coordinated by the UNFCCC secretariat, and the review reports published on the UNFCCC website. This annual reporting and review process has resulted, in most cases, in dedicated teams in developed countries assigned to these tasks that have been working for many years through iterative improvements of their respective national GHGIs.

For non-Annex I (developing) countries, capacity to measure and monitor forest-related fluxes is uneven. For some, GHGIs are compiled by external consultants. Developing countries have historically reported much less frequently, in less detail and historically have not been subject to expert assessments. Most developing countries have submitted only two national communications, and just 32 (out of 153 non-Annex I Parties) have submitted their first Biennial Update Report (BUR), despite a UNFCCC decision that non-Annex I Parties should submit a first BUR by December 2014.

GHGIs of developing countries have not benefitted from sustained feedback through international reviews that help country teams to address these issues. This increases the risk of technical shortcomings that can lead to significant errors and/or omissions in estimating GHG fluxes. Further, data sources and methodologies may not be well documented and definitions may be applied inconsistently across time and across data sources.

An analysis of reporting by 20 non-Annex I countries (with significant forest cover) suggests that reporting on deforestation is relatively complete. However, there are large uncertainties in the reporting categories of "forest remaining forest" and "non-forest to forest". Many developing countries do not have sufficient data to provide robust estimates on whether processes are leading to a long-term decline in carbon stocks of forests (degradation), which may be a significant source of emissions. There are also issues in identifying what area is "managed" versus "unmanaged", and in quantification (often leading to omission) of more complex forest dynamics (e.g. forest regrowth, shifting cultivation). Reporting on pools beyond biomass (e.g. deadwood, litter and soil) is a challenge for many developing countries that do not have regular National Forest Inventory (NFI) cycles, as data on such pools may be old or non-existent. The omission of non-CO_2 gases (common in non-Annex I GHGIs), particularly from forest fires, may also be significant for some countries.

Another source of uncertainty is the use by many developing countries of the older IPCC 1996 Guidelines for GHGIs—which do not allow for an understanding of which forest transitions or pools are covered, unless additional information is provided. However, the situation is changing—developing countries are encouraged to

use the IPCC 2003 Good Practice Guidance, and BUR requirements and the International Consultation and Analysis (ICA) process (a technical analysis of BURs by a team of experts), plus an increasing interest in REDD+, are beginning to produce more frequent reporting by developing countries. These external analyses and assessments are expected to help improve national GHGIs of developing countries.

Completeness of reporting: National GHGIs should include all anthropogenic emissions and removals, but in practice they are not necessarily complete. There are several carbon stock change processes not fully captured by GHGIs of both developed and developing countries. Some are fluxes caused partially by indirect impacts of human activities e.g. permafrost thaw, CO_2 fertilization and nitrogen deposition, temperature variations and droughts. This may be because they are not well understood scientifically or because they occur on land classified as unmanaged.

The impact of natural disturbances often averages out across long time periods. Annually they may cause large variations in the anthropogenic GHG balance of a country. IPCC guidelines are that countries include emissions and subsequent removals associated with natural disturbances on managed land in their national GHGI *reporting.* However, when assessing performance relative to a national target (*accounting*), countries may wish under certain circumstances to exclude a portion of emissions and removals associated with disturbances on the basis that the magnitude of disturbance events may overcome the capacity of humans to take them under control and limit their impact. The Paris Agreement has not yet established guidance on how countries may account for natural disturbances in the context of NDCs although rules have been established under the Kyoto Protocol.

The summary table below is the authors' best selection of the most significant anthropogenic emissions and removals that may not be included in the current status of development of counties GHGIs.

Table 1: GHG forest fluxes that are not required (or may not be included) in current national GHGIs

Should be included in GHGIs	Not required in GHGIs
• GHG emissions and removals in managed lands for which not enough data yet exist (especially developing countries) • Fluxes related to non-living biomass pools (deadwood, litter and soil) • Emissions from drained organic soils • Impacts of CO_2 and N fertilization in managed lands • Emissions and subsequent removals associated with natural disturbances on managed land, including those which are out of human control	• Changes of the C stock equilibrium in unmanaged forest land due to changes in the natural disturbances regime • The natural sink in unmanaged peatlands • CO_2 and N fertilization in unmanaged lands • GHG from fires on unmanaged land

Other fluxes may also be significant, including the Impact of permafrost melting; N_2O emissions from mineralization of soil organic matter where not associated with a net soil organic carbon change; CH_4 emissions from termites and from ruminants, where not part of husbandry systems; and net C stock accumulation in the black carbon pool originating from fires in managed and unmanaged lands. Quantifications of emissions and removals for these fluxes are not well known and are not forest-specific but may help close gaps between inventory data and science studies, although their inclusion may not be a requirement for GHGIs.

Comparing GHGI reporting to independent scientific studies

There is a growing body of publicly available independent data with estimates of GHG fluxes from forests and land to the atmosphere. These include studies of land cover change and fire from remote sensing sources; carbon densities data from various sources; top down global models that estimate emissions and removals combining remotely sensed and ground collected data; and studies that attempt to estimate the impact of fertilization and other components of the terrestrial carbon budget. These studies are often not directly comparable with country reporting to the UNFCCC, nor among themselves—but form the basis of IPCC Assessment Reports (ARs).

IPCC Assessment Reports and country GHGI reporting

The objective of the IPCC's AR process is to provide "a clear and up to date view of the current state of scientific knowledge relevant to climate change". In doing so it reviews scientific literature for its *global* assessment of the physical science basis of climate change (Working Group I) and options for mitigating climate change (Working Group III). The IPCC Task Force on National GHG Inventories has been established to develop internationally agreed methodologies to estimate *national* GHG emissions and removals. These different objectives imply differences between the data, information, and methodologies used in the AR process compared to the guidance used by governments in developing national GHGIs.

The main source of difference between independent scientific studies and national GHGI reporting is the treatment of anthropogenic emissions and removals. Whereas national GHGIs apply the *managed land proxy*, estimates from global model approaches often take a different approach to separate management effects from indirect (or natural) impacts, and include different processes, definitions, and approaches to calculate global emissions and removals from forests. In particular, IPCC AR5 distinguishes emissions and removals due to: (a) land use change, including changes in land cover and certain 'management' processes (such as harvesting and replanting) and (b) the "residual terrestrial sink", estimated by the difference of the other terms of the global carbon budget, and generally assumed to be a 'natural' response of forests and other lands to the fertilizing effects of increased levels of CO_2 and N in the atmosphere and the effects of climate change.

Table 2 compares global estimates of anthropogenic and natural land-related CO_2 fluxes to the aggregate anthropogenic fluxes from land use from national reporting. From Table 2 emerges an *apparent* significant discrepancy between what independent scientific sources estimate as net "anthropogenic" terrestrial emissions and what countries reports for "managed land" (under land use, land-use change and forestry, or LULUCF).

Table 2: Annual GHG fluxes from land: first-order comparison of independent scientific studies versus national reports

Study	**Period**	**Estimate of anthropogenic fluxes (Gt C/y)**	**Residual Terrestrial sink (Gt C/y)**
IPCC AR5, Volume I	(2000-2009)	1.1 $\pm$ 0.8 net land use change (using Houghton bookkeeping model*)	-2.6 $\pm$ 1.2
Le Quéré et al 2015	(2000-2009)	1.0 $\pm$ 0.5 net land use change	-2.4 $\pm$ 0.8
Country reports** (INDC, UNFCCC, FAO)	(2000-2010)	0.2 $\pm$ 0.4*** Whole LULUCF	Not estimated

* Houghton, R. A. *et al.* Carbon emissions from land use and land-cover change. *Biogeosciences* **9**, 5125-5142 (2012).

** From Grassi G., Dentener F. (2015) Quantifying the contribution of the Land Use sector to the Paris Climate Agreement; EUR 27561; doi 10.2788/096422

*** *The +/- is based on an expert-judgment selection of alternative countries' data.*

To investigate further the apparent discrepancies, Table 3 provides estimates of fluxes associated with: (a) "land converted to other land uses" (i.e. land use change, mostly represented by tropical deforestation) and/or deforestation; (b) "land remaining in the same land use" or "forests remaining forests" (in country reporting, mostly represented by removals reported by developed countries); and (c) "land converted to forest land".

The results suggest a partial reconciliation of the discrepancies:

(i) Emissions from deforestation reported by countries (≈0.92 Gt C/yr) reflect reasonably well estimates of land use changes (essentially deforestation) by independent scientific studies (in the table above, ≈1.0-1.1 Gt C/yr). The relatively small difference may be associated with differences between global models vs. country reports in terms of methods used and pools, gases, and processes included.

(ii) Global models tend to estimate forest-related emissions based on net forest area and assume that, unless harvested, forests remaining forests are carbon neutral. Consequently, a large part of the sink that most Annex I countries report under "land remaining under the same land use" (including the large sink in temperate and boreal F→F areas, around -0.53 Gt C/yr) is implicitly included in the "residual sink" by global models (-2.6 Gt C/yr). The same may partly apply also for Non Annex I countries. This means that countries consider this sink at least *partly* human-induced (because reported under "managed land") while global models consider it "natural".

The fact that the forest sink reported by countries is much smaller than the "residual sink" estimated by global top down studies may be explained by several factors, including: (a) uptake in unmanaged land not reported by countries (because considered non-anthropogenic); (b) omissions of fluxes (e.g. regrowth in tropical forests, sink in grassland soils and wetlands, etc.) or pools in managed lands; (c) other factors that are not well understood or captured by the GHGI methodology (e.g. fertilization effects) and therefore not included in national reports. In addition, the residual (terrestrial) sink is a difference in global budget terms and not a direct estimation of GHG fluxes and therefore other factors may explain the disparity with national reports.

Table 3: Comparison of annual GHG fluxes (Gt C/yr) from national reports, disaggregated between 'Land use change' and 'Land other than land use changes'

Study	**Coverage**	**Land use change, or deforestation**	**F→F or L→L**	**NF→F**
Country reports (2000-2010)	All countries	≈ 0.92 deforestation	≈ -0.48 L→L (includes F→F) ≈ -0.75 F→F	≈-0.27
	Annex I	0.04 deforestation	-0.53 F→F, mainly removals from temperate and boreal forests	-0.03
	Non-Annex I (≈ tropics)*	≈ 0.88 deforestation	≈ -0.22 F→F	≈ -0.24
Federici et al 2015 (2000-2010)[1]	Global	1.1 net deforestation**	-0.6 NF→F and F→F (including 0.3 GtC/yr of forest degradation)	

[1] This study derives net C stock changes in F→NF and in NF→F + F→F, by assigning net C stock changes to net area changes reported by countries to FRA for three forest types: *Primary forest, Other naturally regenerating forests* and *Plantations*. For each country, total net C stock change of F→NF and NF→F + F→F corresponds to the net C stock change reported by countries to FRA.

Pan et al. 2011		2.8 tropical gross deforestation	--4.2 NF→F and F→F, excluding unmanaged forests in Canada (118 Mha), Alaska (51 Mha) and West/Central Asia (53 Mha)	
Achard at al 2014 (2000-2010)	Tropics only	0.88 gross emissions using remote sensing data (includes forests and other wooded land)	-0.10 removals from forest regrowth	
Baccini et al 2012[2] (2000-2005)		0.89 net deforestation** and shifting cultivation (excluding soils)	0.09 net emissions from industrial logging and fuelwood harvest	
Harris et al 2012 (2000-2005)		0.81 gross deforestation using remote sensing data		

* In non-Annex I country reports to UNFCCC using the 1996 IPCC Guidelines is often very difficult to distinguish between F→F and L→F. Numbers in this table should be considered a first estimate.
** Net deforestation estimates include a portion of fluxes from the NF→F category.

Even though it appears that global estimates of emissions from deforestation by independent studies match well with aggregated forest emissions from national GHGI reporting, this may not indicate accuracy by either source of information. It is possible that global or pan-tropical aggregates are averaging out actual differences in estimations. Studying these differences could lead to improvements on both sides of the comparison. For example, in addition to the definition of "anthropogenic" that lead to differences in national and aggregate estimates of forest-related GHG fluxes, the following may also result in quantified differences (and are elaborated in Section 3.3 of the report):

- **Forest definition**: Differences may include parameter values (e.g. minimum area, height, crown cover, etc.); use of land *cover* versus land *use*; or the exclusion of some types of tree cover (e.g. agricultural production systems).

- **Activity data**: In the case of land-use changes, these data are normally provided in hectares. Forest definition and the differentiation between managed and unmanaged land are two factors that can substantially influence activity data. Additional reasons for differences include: spatial resolution; remote sensing analysis approach; temporal resolution; or sampling vs. wall-to-wall coverage.

- **Emission factors:** Emission factors may vary based on which pools are included, as well as whether national estimates or default values are used. They may also vary based on the stratification used (given emissions and removals are affected by climate, soil, vegetation, management practices), or the methods used to calculate them.

Conclusions

The goals agreed in Paris cannot be met without a significant contribution from forests. Understanding forest-related GHG fluxes, however, can be challenging. Independent scientific studies—which are the basis of the IPCC's periodic Assessment Reports aimed at providing global flux estimates, including from the land sector—

[2] Estimate based on the Baccini et al. 2012 analysis as re-assessed in "Progress Towards A Consensus on Carbon Emissions from Tropical Deforestation", by Woods Hole Research Center and Winrock International (2012), and information from IPCC WG3 AR5 Figure 11.8.

often use different definitions and methodologies than those included in the IPCC Guidelines for National GHG Inventories, whose aim is to provide internationally agreed, standardized guidance to countries in preparing their national GHG inventories. This can result in differing quantifications of anthropogenic emissions and removal from forest lands.

A significant difference between independent scientific studies and national reporting is the methodology used to distinguish anthropogenic from natural sources of emissions and removals. Other differences may arise due to differences in forest definition, sources of activity data, emission factors, or the use of models to produce global, regional and/or biome results. Coverage of pools and greenhouse gas source categories may also not be the same when comparing scientific papers with national reports, but also when making comparisons between scientific papers. When comparing estimates from scientific journals to those in national GHGI reports, therefore, issues that need to be considered include:

- approaches to separate natural from human induced fluxes,
- estimation methods used,
- differences in forest definition,
- pool coverage,
- whether regrowth is included,
- whether and how natural disturbances are included.

Estimates from studies published in scientific journals and national GHGI reports *are both the result of* science-based methods, and can in principle be reconciled, or the differences understood. It is important to understand where differences among estimates that seemingly should agree are coming from. Once understood, the numbers should agree to within the quantified uncertainties. Likely sources of differences include methodological approaches and assumptions and inclusiveness of some of the fluxes.

The periodic "global stocktake" called for by the Paris Agreement will require tracking of the role of forests in achieving the 2 °C or 1.5 °C goal. This requires robust country estimates, and in this context it is important to achieve greater comparability between scientific studies and national reports. In order to make such comparisons, each source of information would need to provide transparent documentation on how estimates were derived.

Starting from the scientific side there should be greater awareness of the information contained in national reports and the possibilities of using it. Providing information disaggregated by national boundaries and by administrative region will be helpful, and it will be useful to consider IPCC definitions when considering pool coverage. Scientific papers that provide information compatible with IPCC inventory methods should be communicated to IPCC via the Emissions Factor Database. The scientific community could also help to distinguish and clearly document those fluxes that are outside of the GHGI framework but are nonetheless of substantial importance for tracking the global carbon budget in the context of the Paris Agreement.

From the national GHG inventory side there is considerable scope for improving forest-related estimates of GHG fluxes that would enhance the understanding of countries' NDCs, as well as overall progress towards the global goals contained in the Paris Agreement. There should be greater awareness of scientific work that is consistent with IPCC methods that can be used for independent verification. This awareness should be further encouraged by the inventory review and assessment process. Countries not having country specific data should use IPCC default methods to extend the range of carbon pools covered. Countries which have significant areas of unmanaged land may wish to include information on emissions and removals on these lands even though they are not included in national greenhouse gas inventories. Countries need to continue to improve transparency of

information reported to allow, as far as practicable, for replicability of GHG estimates. Spatial boundaries and statistical estimation methods should be clear, so comparisons can be made as closely as possible. More recent IPCC guidance (at least 2003 Good Practice Guidance) should be used, consistent with encouragement in COP decisions.

Finally, the IPCC in future AR or Special Reports may provide clarification of differences such as those highlighted in this report. Where possible, it may also consider greater consistency between definitions and methods used when estimating forest-related GHG fluxes for Working Group I and III reports and comparability with guidance provided by the IPCC Task Force on GHG Inventories.