GHG FLUXES FROM FORESTS

An assessment of national GHG estimates and independent research in the context of the Paris Agreement

June 2017

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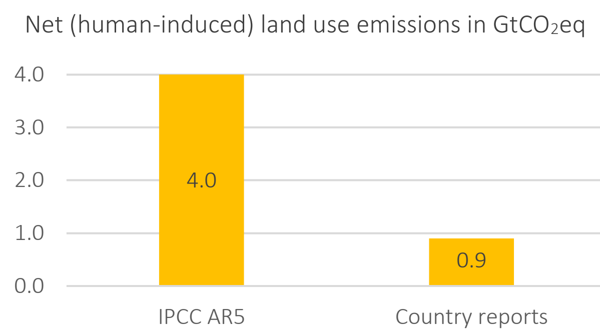
Contents

Executive Summary

The Paris Agreement provided an international structure and processes through which the world can avoid dangerous climate change. It also brought together 197 countries to agree on new global goals—including reaching a balance in anthropogenic greenhouse emissions and removals in the second half of the century and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels to significantly reduce the risks and impacts of climate change. Neither of these goals can be met without a large contribution from forests.

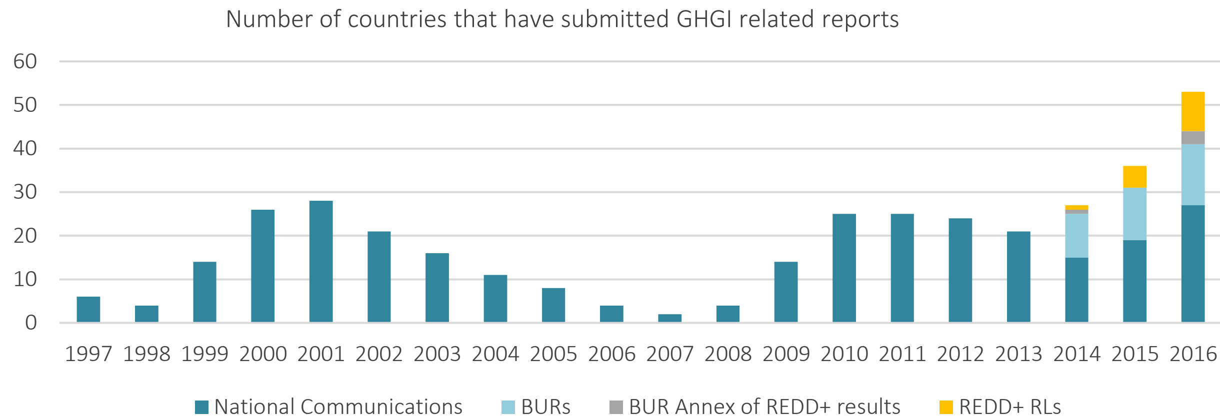
The periodic Global Stocktake—called for under the Agreement to occur every five years—offers an opportunity to take stock of the collective progress countries are making towards such goals. This process can be supported by better estimations in national GHG reporting and more transparent and comparable global estimates of the GHG balance. In addition, progress towards Paris Agreement goals cannot be properly assessed without understanding why national reporting on forest fluxes diverges from independent research and global carbon budgets.



Currently, there is a significant difference in what independent studies estimate and claim is the human-induced contribution of land-use emissions (and removals) to the atmosphere compared to national GHG reports. The most recent IPCC Assessment Report suggests this figure is about 4.0 $GtCO_2eq$/yr for the period 2000-2009, whereas countries are reporting net emissions closer to 0.9 $GtCO_2eq$/yr. Most of the emissions in the "land use" category are forest-related fluxes. If the basis for the Global Stocktake is information from IPCC Assessment Reports *and* national GHG inventory reports, we need to understand this discrepancy and seek methods to develop meaningful comparisons.

One of the critical differences between many independent sources of forest flux estimations and national GHG estimates of forest fluxes (based on IPCC Guidelines for national GHG inventory reports) is the question: "What is labeled as anthropogenic?". The IPCC Guidelines provide guidance to countries to only include fluxes on "managed lands" (defined as "land where human interventions and practices have been applied to perform production, ecological or social functions") in their GHG inventories as a proxy for anthropogenic emissions and removals. By contrast, independent research may not consider all processes on managed lands as anthropogenic (e.g. C stock changes due to CO_2 fertilization or N deposition), and therefore not estimate them, or consider them part of the "residual sink" (as in the case of IPCC AR reports). Alternately, research may be focused on estimating all fluxes (i.e. "what the atmosphere sees") rather than just anthropogenic fluxes. There are gigatons of fluxes occurring on unmanaged lands that are not included in national GHG inventories—which are focused on measuring human contributions to atmospheric GHG concentrations.

Another reason why there is a discrepancy between independent studies and country reports is incomplete reporting by countries due to capacity gaps—particularly by developing countries that have not had the opportunity to undergo regular review processes (that have had a significant impact on improving developed country reports). While estimates of emissions from gross deforestation have improved significantly in the past few years, partly from increased REDD+ related investments, many countries still do not measure carbon uptake in existing forests, and the emissions and removals from the establishment of new forests, harvested wood products, forest degradation and forest fires. Over time, with new requirements for technical analysis of Biennial Update Reports and if incentives are provided for REDD+ performance, we should expect improvements in developing countries' forest-related estimates in national GHG inventories.



Other reasons why independent estimates may differ include use of different data sets or definitions. For example, countries use national definitions of forests and land use, whereas global datasets may use a single definition or not distinguish between different tree cover types. How forests and forest change are detected and carbon stocks measured (e.g. satellite data, land use registration information, national forest inventories, etc.) may also explain differences. The inclusion of different carbon pools (e.g. above and below-ground biomass, deadwood, litter, and/or soil) can also create discrepancies, as well as whether (and how) harvested wood products or non-CO_2 gases from fire are included.

In conclusion, independent studies and national reporting of forest fluxes are currently not easily comparable. Awareness in the scientific community of information contained within, and methods used by, national GHG inventories can enhance the policy relevance of independent research. For example, such research could disaggregate estimates to make them comparable with country reports. This could encourage more cooperation between the two communities at national level. Future IPCC reports should also seek to describe the differences between independent studies and national GHG estimates.

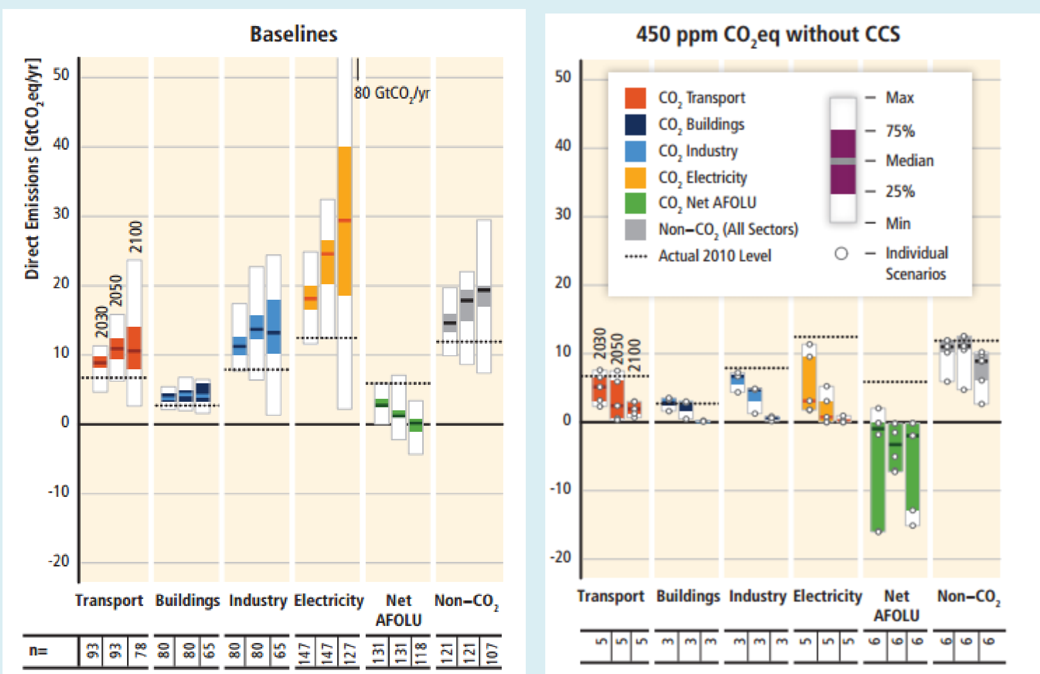
Sources of information (including both independent research and national reports) should provide transparent documentation on how estimates were derived. And improving the capacity of countries to estimate and submit more complete GHG inventories should be a priority. Implementing these recommendations can ensure that reporting on forest sector emissions and removals are credible and that the mitigation potential of forests—critical for avoiding dangerous climate change—will be achieved.

1. Introduction: Objectives of the Study

Countries agreed at the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in December 2015 on a number of climate change mitigation goals: to hold the increase in global average temperature to well below 2°C, to reach global peaking of greenhouse gas (GHG) emissions as soon as possible, and to achieve a balance between anthropogenic emissions to and removals from the atmosphere in the second half of this century. Achieving these goals will require a significant contribution from forests (Houghton et al, 2015; IPCC AR5 Synthesis Report, 2014)—not only through reducing deforestation, but also by maintaining and increasing the global sink capacity of forests, including through increasing forest area, improved forest management, restoring degraded forest lands, and improved use of wood products.

Forests in a 2° scenario

According to the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, forests are critical to limiting the rise in global temperatures to below 2 degrees (i.e. staying within 450 parts per million CO_2eq in the atmosphere—as in the figure to the right below), particularly if Carbon Capture and Storage (CCS) is not an available technology. In the figure below, forests are included within the AFOLU (agriculture, forests and other land use) sector.



Source: IPCC, 5th Assessment Report, Working Group III, Summary for Policymakers, Figure SPM.7, page 18. The bars in the graphs correspond to the time periods in which the assumed mitigation would need to materialize (2030, 2050, 2100); the numbers at the bottom of the graphs refer to the number of scenarios included in the range which differs across sectors and time due to different sectoral resolution and time horizon of models.

GHG exchanges between the land and the atmosphere are generated by anthropogenic and natural processes. For the land sector, country GHG reporting to the UNFCCC—mainly through national GHG inventories (GHGIs)[1] —is intended to focus on *anthropogenic* emissions and removals rather than non-anthropogenic GHG exchanges between the land and the atmosphere. Therefore, GHGIs seek to capture the overall net emissions contribution (both direct and indirect) from human actions to atmospheric GHG concentrations, as a basis for quantifying the mitigation potential of each country. GHGIs also track mitigation achieved through policies and measures implemented, and inform further mitigation efforts. In the context of the Paris Agreement, national GHGIs are critical for providing transparency on progress toward achieving nationally determined contributions (NDCs), and to inform the progression of successive NDCs[2].

In addition to national GHGI reporting, there is a growing body of independent research produced by the scientific community that seeks to quantify and improve the understanding of GHG fluxes from forests. These include studies of land cover change and fire; forest carbon stocks; global models that estimate emissions and removals by combining satellite and ground data; and studies that estimate the impact of CO_2 fertilization and other components of the terrestrial carbon budget[3]. Often such studies focus on the full set of GHG fluxes from land, including (without disaggregation) anthropogenic and natural fluxes.

This assessment seeks to:

a) Clarify what forest-related emissions and removals are (and are not) included in national reporting, in particular through GHGIs (Section 2);
b) Compare national reporting to independent research, and provide an explanation of why and how they differ (Section 3);
c) Provide recommendations on how to improve understanding of the role of forests in the global carbon budget (Conclusions, Section 4).

This study should be considered as a first step towards a better collective understanding of the forest-related information available to assess progress toward delivering on the goals of the Paris Agreement, as well as potential improvements in country-level reporting.

[1] Although this document deals mainly with GHGIs, occasionally other country reports to UNFCCC are discussed (e.g. FREL submissions).
[2] Paris Agreement, Article 4, state that "Each Party's successive NDC will represent a progression beyond the Party's then current NDC and reflect its highest possible ambition…".
[3] Section 3 of this paper provides several citations of such research; it is not the aim of the paper to assess such research in depth, but rather to identify and explain discrepancies among them and with national estimates of forest-related GHG fluxes.

2. National GHG inventory reporting

2.1. The context and objectives of national reports

The ultimate objective of the UNFCCC is to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNFCCC Article 2). Reporting requirements of the UNFCCC aim to provide the Conference of the Parties (COP) with information to assess the overall effects of the measures taken [by each Party] pursuant to the Convention … as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved (UNFCCC Article 7).

Since national GHGIs are developed to enable the assessment of countries' contribution to atmospheric GHG concentration, and to global mitigation efforts, their scope is limited to estimating *anthropogenic* emissions and removals. Inclusion of non-anthropogenic sources of emissions and removals in GHGIs would complicate the assessment of mitigation actions and the quantification of emissions and removals associated with policies and measures. However, available science does not allow for full separation between anthropogenic and non-anthropogenic emissions by sources and removals by sinks in the land use sector, which has led the IPCC to develop (in its Guidelines for National GHGIs) the "managed land proxy" (see Section 2.2).

Country Reporting to the UNFCCC

All signatories to the UNFCCC (197 Parties have ratified the Convention, including 196 countries plus the European Union) are required to report GHG emissions and removals through submission of national GHG inventories (GHGIs). GHGIs are produced using guidance and methodologies developed by the Intergovernmental Panel on Climate Change (IPCC). These inventory methodologies were initially produced in 1995 with important updates in 1996, 2000, 2003 (Good Practice Guidance for Land Use, Land-Use Change and Forestry), 2006 and 2013[4]. GHGIs cover a range of economic sectors (e.g. energy, industrial processes, agriculture, land use, and waste). This report focuses on emissions and removals from forests, which is part of the land use sector.

GHGI reporting requirements have been substantially different between developed and developing countries in terms of frequency and quantity of information to be reported. Developed countries submit National Inventory Reports annually, in addition to reporting through National Communications (NCs) and Biennial Reports (BRs), all of which are reviewed. For developing countries, the GHGI is included as a chapter in the National Communications, and from 2014 also a summary of the GHGI is included in the Biennial Update Reports (BURs)[5]. Developing countries also may submit, voluntarily, REDD+ reference levels and a REDD+ annex to their BUR which include information on forest-related fluxes only.

[4] These include both IPCC Guidelines and Good Practice Guidance for National GHG Inventories; from here on in the report we simply refer to these sources collectively as "IPCC Guidelines".

[5] In 2010, Parties to the UNFCCC decided that developing countries should submit BURs containing updates of national GHGIs every two years and National Communications every four years. In 2012 the COP adopted guidelines for the BURs and decided that non-Annex I Parties should submit their first BUR by December 2014; as of May 2017, 36 countries had submitted a first BUR and 5 submitted a second BUR. For more information on BURs, see: http://unfccc.int/national_reports/non-annex_i_natcom/reporting_on_climate_change/items/8722.php

Developed country reporting of GHGs	Developing country reporting of GHGs
National Communications (every 4 years)*	National Communications (every 4 years)
Biennial Reports (every 2 years)*	Biennial Update Reports* (every 2 years, with flexibility for Least Developed Countries). The BUR may include a REDD+ annex (voluntary, forest-related emissions and removals only)
National Inventory Reports (every year)*	REDD+ Reference Levels* (voluntary, forest-related emissions and removals only)

**Reports that undergo review (i.e. international assessment or analysis) procedures.*

National GHGIs are developed by country experts and those from developed countries are extensively reviewed by international experts chosen from a roster of government nominated experts, and assisted by the UNFCCC secretariat. Developing countries' GHGIs do not undergo the same procedures and are currently checked only for transparency and without the same complete list of required information. However, REDD+ reference levels and REDD+ Annexes to the BURs do undergo a more detailed technical assessment. The recent operationalization of the BUR requirement and the International Consultation and Analysis[6] (ICA) process, plus improved forest monitoring as part of emerging REDD+[7] efforts, are resulting in observable improvements in GHG forest flux estimates by developing countries. Over time, the ICA process and Technical Assessment of forest reference emission levels are expected to continue this process of improvement.

More recently, the Paris Agreement established a transparency framework (Article 13) whose objectives are to build mutual trust and confidence and to promote effective implementation and to provide a clear understanding of climate change action … including clarity and tracking of countries' progress towards achieving Parties' individual nationally determined contributions. The purpose of the framework is also to inform the periodic global stocktake (see box below). This framework is expected to build upon country GHG inventory reporting under the UNFCCC. The Paris Agreement's emphasis on transparency could provide a stimulus for improved, and increased transparency around, emission (and removal) estimates.

The Paris Agreement's Global Stocktake

The Paris Agreement creates a process through Article 14 to take stock periodically of the implementation of the Agreement and to assess the collective progress towards achieving its objectives, which include holding the increase in global temperature to well below 2°C (Article 2), reach global peaking as soon as possible, and achieve a balance between anthropogenic sources and removals by sinks in the second half of this century (Article 4). It states that this should be done in light of the best available science. The first official stocktake will be in 2023 and every 5 years thereafter, with a first 'facilitative dialogue' to take place in 2018, informed by a Special IPCC report on the assessment of impacts of a 1.5°C rise in global warming and related global GHG emission pathways.

The outcome of the Global Stocktake should include an assessment of the gap between existing country pledges and the net emission reductions required to achieve the Paris Agreement's long term mitigation goals.

[6] Also in 2010, Parties decided to conduct international consultation and analysis (ICA) of BURs; the modalities and guidelines were adopted the following year and include a technical analysis of each BUR by a team of technical experts. As of May 2017, 32 countries have undergone a first technical analysis. For more information on the ICA process, see: http://unfccc.int/national_reports/non-annex_i_natcom/reporting_on_climate_change/items/8722.php

[7] REDD+ stands for "reducing emissions from deforestation, reducing emissions from forest degradation, conservation of forest carbon stocks, sustainable management of forests, and the enhancement of forest carbon stocks" and is a concept developed under the UNFCCC that involves "policy approaches and positive incentives" including results-based finance.

2.2. The managed land proxy

The 2006 IPCC Guidelines[8] 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 key rationale for this approach is that emissions and removals in managed lands are predominantly of anthropogenic origin (both direct and indirect[9]) and that the contribution from natural effects is assumed to average over time. This proxy was introduced to overcome the challenge of providing a practicable and broadly applicable methodology to separate direct human-induced effects from indirect human-induced and natural effects.

Under the managed land proxy, all GHG fluxes from areas that countries designate as "unmanaged" are neither estimated nor reported. According to the most recent IPCC guidance, managed land is *land where human interventions and practices have been applied to perform production, ecological or social functions. All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time*[10]. Once a human intervention occurs in an unmanaged land and results in anthropogenic GHG fluxes, the land should be thereafter considered managed land[11] and emissions and removals, including any that may have been caused by the first human intervention, or those that determined the suitability of land for management (e.g. forest fires), reported.

Any comparison between national GHGIs and independent studies for countries with significant unmanaged forest area would need to take into account that the former may refer only to managed land estimates while the latter could include all lands. Table 1 shows which of the top 10 countries (and the EU) by forest area have distinguished between managed and unmanaged forest.

Table 1: Managed and Unmanaged Lands in top 10 forested countries and the EU by area

Country	Total forest area as reported in GHGI (M ha)	Forest area considered managed (M ha)	% Unmanaged	% of forest area identified as primary forest[12]
Russia (CRF, 2017)	897	685	24%	33%
Brazil (3rd NC, 2016)	494	235	52%	41%
Canada (NIR, 2016)	348	232	33%	59%
United States (CRF, 2016)	304	294	3%	24%
China (NC, 2012)	195	195	0%	6%
European Union (CRF, 2016)	165	162	2%	7%
DRC (3rd NC, 2015)	150	150	0%	67%
Australia (CRF, 2016)	103	103	0%	4%
Indonesia (BUR, 2016)	Area estimates not provided			51%
Peru (3rd NC, 2016)	74	49	34%	89%
India (BUR, 2015)	70	70	0%	22%

[8] The concept of the managed land proxy was first introduced in the 2003 Good Practice Guidance for LULUCF.
[9] Direct-human induced effects include land-use changes, harvest and other management practices. Indirect-human induced effects include: climate change induced change in T°, precipitation, and length of growing season; human-induced increases in CO_2 and N deposition; impact of air pollution (e.g. ozone, etc.); changes in natural disturbances regimes. Natural effects include interannual variability and natural disturbances. For more details: http://www.ipcc-nggip.iges.or.jp/public/mtdocs/pdffiles/0905_MLP_Report.pdf
[10] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 4, Chapter 1, page 1.4.
[11] For example, deforestation (but not temporary forest loss due to natural disturbances such as fire and flooding) occurring in unmanaged land is mostly direct human-induced and therefore should be captured in GHGI reporting.
[12] Based on country reporting to FAO FRA 2015.

Many developing countries, including China, the Democratic Republic of Congo (DRC), India and Indonesia do not refer to either managed or unmanaged land in their National Communications and appear to imply all forests are included in the reporting. For the case of China and the DRC, this can be the consequence of having used the 1996 IPCC Guidelines that do not use the managed land proxy. For BUR reporting, the 2003 IPCC Good Practice Guidance for LULUCF are required, and therefore all countries are expected to apply the managed land proxy under the Paris agreement.

It is worth noting that the definition of "managed land" is not prescriptive and therefore countries define it according to their specific circumstances (see examples in Table below).

Table 2: Examples of the Application of the Managed Land Proxy

Country	Application of the Managed Land Proxy
Brazil	Brazil assumes all forest area loss is due to management activities and therefore reports on associated emissions. It also considers as managed: managed forest (defined as indigenous lands and lands included in the National System of Protected Areas), secondary forests, selectively logged forests (in Amazonia only), and reforested areas. Removals are reported from all managed forest land. Brazil also reports emissions from conversion of forests with higher C content to lower C content (e.g. secondary forests, selectively logged forests) regardless if designated as managed or unmanaged.
Canada	Canada classifies forests as managed/unmanaged based on the occurrence of management activities and on the level of protection against disturbances. Managed forest areas include all operational forest management units, timber supply areas, tree farm licenses, industrial freehold timberland, private woodlots and any other forest land where there is active management for timber or non-timber resources, as well as forest areas where there is intensive protection against natural disturbances.[13]
Peru	Peru classifies forests in conservation areas, forests in indigenous reserves and community lands, and forests under concession for harvesting or other uses (e.g. ecotourism) as managed forest land.[14]
Russia	The Russian Federation defines managed forests as forests in which systematic human activities are carried out to fulfill the necessary social, economic and ecological tasks to ensure rational, continuous and sustainable forest management, reproduction, protection and monitoring of forests. This includes forested areas with an organized set of economic activities such as conducting regular forest inventories, long-term planning, determination of annual allowable cut and accounting for economic purposes and environmental functions as well as forest protection and reforestation activities that ensure the stabilization and reduction of losses from fires and other disturbances.[15]
United States	All lands in the United States are considered managed except some areas in the interior of Alaska. In Alaska, managed areas include: a 10-km buffer around settlements, roads and train corridors; lands with active or past resource extraction, including a 3,300 meter buffer around petroleum extraction and 4,000 meters around mining sites; lands with active fire management; and protected areas where active management for resource extraction, recreation, or to suppress natural disturbances is present. While the US identifies many areas in the interior of Alaska as managed, these are not (yet) estimated or reported in the GHGI.[16]

[13] Canada's 2017 national GHGI.
[14] Peru's 3rd National Communication (2016), Table 2.3.
[15] Personal communication with Russian official responsible for the GHGI.
[16] United States' 2017 National Greenhouse Gas Inventory.

Specific emissions and removals related to forests that would be excluded from a GHGI *to the extent that they occur on unmanaged* land include:

a) **Carbon removals**, such as carbon (C) sequestration from forest growth and re-growth after natural disturbance or from new forest expansion due to climate change-induced treeline shifts; fertilization effects due to increased atmospheric CO_2 or atmospheric nitrogen (N) deposition; and accumulation of carbon in dead organic matter (e.g. organic matter in peat soil, black carbon from fire);

b) **GHG emissions,** including from wildfires and other disturbances (such as pest outbreaks), mortality caused by climate change and associated impacts, for example, on peat lands from permafrost thaw.

These emissions and removals can be potentially significant, and may explain some of the apparent disparities between GHG reporting to the UNFCCC and independent studies (see Section 3). Several examples of emissions and removals on unmanaged lands are included in Table 3 below.

Table 3: Examples of emissions and removals on unmanaged lands

Country examples	Canada	Canada does not include in its GHGI emissions from fires on unmanaged land, which data for 1990 to 2014 suggest accounts for two-thirds of the total area affected by fires[17]. Using an average 132 tCO_2e/ha[18], there were estimated emissions of ~**353 $MtCO_2e$/yr** in unmanaged areas during this time period. Removals from expected regrowth following such disturbances on unmanaged lands are also not included in the GHGI.
	Russia	Kurgova et al (2010) estimate an annual sink of **-0.4 Gt CO_2eq** (in the soil organic matter pool of abandoned agricultural land under natural conversion to forest) which Russia considers as unmanaged forest[19].
	Brazil	Brazil's 3rd National Communication reports a net sink, likely due to N and CO_2 fertilization effects, from primary forests in designated indigenous lands and most protected areas[20]. From this, a potential sink of -**288 $MtCO_2e$/yr**[21] associated with carbon stock accumulation on unmanaged forest land (254 million hectares in 2010 due to a different legal status) can be estimated that is excluded from the GHGI.
Regional examples	Canada, Russia and the US	GHG fluxes from forested peatlands that are considered unmanaged are likely significant; currently peatlands as a whole (both forested and non-forested) are a net sink and both may help explain a portion of the "missing sink" (see Section 3.2). However, with a warming climate, these areas may turn into a source if water levels decrease (due to higher evaporation or lower precipitation) or permafrost thaws (Swindles et al, 2015)[22], or may increase their sink capacity from a longer growth season or N or CO_2 fertilization effects (Charman et al, 2015).

[17] This value has been calculated by comparing data on the Canadian national dataset on burnt areas associated with forest fires and the area reported in the 2017 GHGI.

[18] Figure from Canada's forest management reference level (FMRL) submission (2011), the wildfire emission factor used to calculate the "background level of natural disturbance", derived from Canada's 2011 NIR.

[19] Because such forest expansion occurs on unmanaged land, the GHGI does not report associated emissions and removals although it reports the area subject to this expansion.

[20] Brazil's 3rd National Communication, Vol. 3, page 145.

[21] Estimated from Brazil's 3rd National Communication, Tables 3.81-3.101.

[22] In this paper the authors report a reduction in carbon accumulation (i.e. a GHG source) in peatlands on permafrost that is subsequently followed by a new phase of carbon accumulation after the peat bog collapses and is transformed into an arctic fen with thaw pools.

	Unmanaged Boreal and temperate forests	According to Luyssaert et al (2008) these forests sequester about -1.3 ± 0.5 Gt of C per year. The authors indicate that over 30% of global forest area is unmanaged[23] primary forest, containing the world's remaining old growth forests. Half of the primary forests (covering 600 million ha) are located in boreal (near the Arctic) and temperate regions in the Northern Hemisphere. Some of these areas are likely to be included in national GHGIs, for instance, forest areas under conservation.
	Unmanaged tropical forests	Houghton (2012b) estimates the sink of "intact" tropical forest at 1.19 Gt C. It is not straightforward to compare this with forest area reported as unmanaged in GHGIs, as the application of the managed land proxy may not correspond to the same areas considered intact even though it is likely that most of the intact forest is not subject to anthropogenic impacts.

Large differences in reported fluxes may arise if land which is remote (and therefore not subject to significant human intervention) is treated in the same way as land that is subject to significant intervention. For example, the DRC's GHGI24 does not separate out unmanaged lands, implying removals from forest growth of approximately of -270-280million tCO2e/yr. Although not explicit, one may infer that the GHG inventory uses average increment factors of around ~0.5 tC per year and hectare, applied over the entire forest area. The IPCC guidance recommends using such increment factors for regrowth in managed forests where also other activities such as harvesting or human-induced disturbances occur; applying them on primary forest lands neither harvestable nor disturbed results in overestimating actual carbon uptake[25].

2.3. GHGI capacity in developed and developing countries

Generally speaking, all 43[26] Annex I (developed) countries provide national GHGI reports annually, the first submitted in 1996. Such reports are reviewed by technical experts coordinated by the UNFCCC secretariat, and the review reports are published on the UNFCCC website.

In 2010 the COP decided[27] that non-Annex I (developing) countries are to submit National Communication reports every four years and Biennial Update Reports every two years (with additional flexibility for Least Developed Countries[28]). As of May 2017, most developing countries have submitted at least two National Communications, including several large forest countries such as Bolivia, Colombia, India, and Indonesia. Thirty-seven out of 153 developing countries have submitted three reports (including Brazil, the DRC and Peru) and only Mexico has submitted a 4th and 5th report. As of May 2017, 36 non-Annex I countries, or about a quarter of developing countries, have submitted their first BUR (four of which include a Technical Annex of REDD+ "results" against a submitted REDD+ reference level); and five countries, including Brazil, have submitted a second BUR (one of which include a Technical Annex with REDD+ results).

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[23] For Luyssaert et al. the term unmanaged means forest is not subject to any commercial exploitation activity; this does not coincide with the IPCC definition if the country includes forest management activities other than commercial exploitation to qualify land as managed (e.g. protected areas). Since most of the areas indicated by Luyssaert et al occur in Canada, Russia and United States, the area reported by the countries as unmanaged forests is probably a subset of the unmanaged area of reported in the study.

[24] The DRC's most recent GHGI can be found in its 3rd National Communication (April 2015); removals from forests reported in Table 3.9.

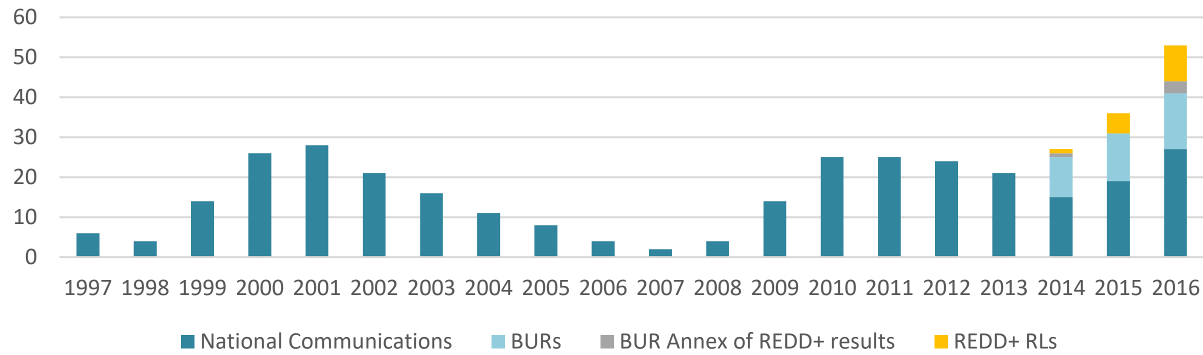
[25] See accompanying case study on the Democratic Republic of Congo.

[26] For the purposes of this paper, we include Kazakhstan as an Annex I country as its GHGI reporting is more akin to an Annex I country; however, it is considered only an Annex I country under the Kyoto Protocol (and as a non-Annex I country for the purposes of the Convention)

[27] See Decision 1/CP.16 para 60.

[28] There are currently 48 least developed countries in the UNFCCC, see: http://unfccc.int/cooperation_and_support/ldc/items/3097.php.

Table 4: Number of country submissions of GHG estimates by developing countries to the UNFCCC



For most developed countries (and some developing countries), data reported on forests are generated by well-established national systems (often designed for reasons other than measuring only carbon fluxes) that typically employ technical experts and researchers within government departments or agencies. Their national forest monitoring systems collect data regularly as part of national statistical processes. Developed countries report annual GHGIs to the UNFCCC and therefore typically set up dedicated teams for this task, often comprised of government staff who have been working for many years through iterative improvements and drawing lessons from the international review process.

By contrast, developing country capacity has historically been uneven. GHGIs often are compiled ad hoc by external consultants, and without necessarily generating lasting capacity among local or government staff or becoming part of the country's national statistical processes. Also, GHGI compilation has not benefitted from sustained feedback through international reviews. As a consequence, technical shortcomings that can lead to significant errors and/or omissions in estimating GHG fluxes appear in many developing countries' GHGIs that otherwise would be detected and addressed through such a process. Further, data sources and methodologies may not be well documented and definitions may be applied inconsistently across time and across data sources. The situation is changing—for example, the robustness of several developing countries' GHGIs (e.g. Brazil, Chile) can be considered as well within the range of Annex I GHGIs.

Developing countries have recently committed to regular GHGI reporting, through the BURs, and begun to develop capacities with encouraging early results. Neeff et al (2015) explored measurement, reporting and verification (MRV) capacity development across 12 countries and concluded that significant progress could be observed. This fact provides reassurance regarding the soundness of development agencies' and partners' significant investments—as well as the commitment of developing countries—in improving MRV capacity. Another study (Romjin et al, 2015) explored progress in 99 countries over the last ten years and found that the number of countries with good or very good forest area change monitoring systems had increased from 69% to 83%. Similarly, diffusion of good to very good forest inventory capacities had increased from 38% to 66%. Much of the observed progress in forest reporting may be driven by increased efforts in the REDD+ context; the same level of progress does not necessarily apply to other land categories within the GHGI.

2.4. Completeness of reporting

A complete GHGI reports on all significant emissions and removals on managed lands for which the IPCC provides methodologies for estimation. The IPCC Guidelines allow countries to start with relatively simple methods using default factors (Tier 1) and to improve estimates over time by developing country-specific factors (Tier 2) or to use modeling approaches (Tier 3) as they improve and more accurately report all anthropogenic emissions and removals. This approach should enable all countries to provide complete GHGIs, and to overcome differences in capacity for GHG estimation.

However, in practice, estimates among national GHGIs differ in coverage and quality. There are many instances where forest-related GHG fluxes are missing from currently reported GHGI data. In most cases, an incomplete inventory is due to a lack of capacity to report on emissions and removals from all activities, gases, and C pools. The sub-sections below analyze areas where GHGI reporting currently tends to be incomplete.

2.4.1. Reporting on forest-related categories

Forest-related emissions and removals are estimated and reported in GHGIs in the following categories[29]: (a) Forest land converted to Non-Forest land (F→NF), such as F→Cropland, or F→Grassland; (b) Non-Forest land to Forest land (NF→F); and (c) Forest land remaining Forest land (F→F). National reports are not always comprehensive in reporting these categories, as illustrated in Table 5. Reasons for why some categories are not reported vary by country and can be due to capacity constraints including in the application of the methodologies or lack of data. Sometimes a category is not reported because emissions or removals in the category are considered insignificant.

Table 5: Number of countries reporting on forest-related categories, based on reports to the UNFCCC

	F→NF	F→F	NF→F
Annex I[1] (41)	38[2]	41	38[2]
Non-Annex I (153)			
≈ 20 non-Annex I forest countries analyzed – listed below[3]	19[4]	≈15	≈14
other Non-Annex I	60% still use IPCC 1996 Guidelines which does not classify transitions in this way – see text		

[1]Annex I excluding Malta (with negligible forest) and Monaco (with no forest) and including Kazakhstan; information from 2016 GHGI submissions to the UNFCCC (for the year 2014).
[2]Not reporting: Belarus, Cyprus, Kazakhstan.
[3]Information from NCs and BURs; countries analyzed to approximate reporting of developing countries include: Brazil, Indonesia, DRC, Bolivia, Mexico, Colombia, Argentina, Angola, Peru, Myanmar, Venezuela, Mozambique, Thailand, India, Paraguay, China, Madagascar, Cambodia, Vietnam, Laos; information is from NCs, BURs, INDCs, or REDD+ Reference Level (FREL) submissions. These countries were selected based on a combination of top countries in terms of forest cover and countries where enough information was available.
[4]Not clearly reporting: India

Annex I countries tend to report on all forest categories (although not necessarily for all C pools), except for a few countries (e.g. Belarus, Cyprus and Kazakhstan) due to lack of activity data. Almost all 20 non-Annex I forest countries analyzed report on deforestation (F→NF). These estimates are currently in

[29] According to approaches 2 and 3 of the more recent version of the IPCC Guidelines and Good Practice Guidance.

various stages of review via the International Consultation and Analysis process. The greatest uncertainties in reporting are likely to be related not to deforestation, but to forest remaining forest (including forest degradation, see later) and to the identification and quantification of certain forest dynamics (e.g. forest regrowth, shifting cultivation).

Another source of uncertainty is the continued use of the IPCC 1996 Guidelines (by some developing countries), which does not allow an unequivocal classification of areas in the three categories in Table 5[30], unless additional information is provided. In 2011, however, the COP agreed that developing countries, when submitting BUR reports, are to use the 2003 Good Practice Guidance[31], which should enhance transparency of future reporting.

1996 IPCC Guidelines vs. 2003 IPCC Good Practice Guidance for LULUCF and 2006 IPCC Guidelines as relates to LULUCF

Developing countries are requested by the COP to use the 1996 IPCC Guidelines for preparing GHGIs in their NCs. Starting in 2014, they are requested to use the 2003 Good Practice Guidance (GPG) for LULUCF in preparing GHGIs in their BURs. Furthermore, under REDD+, countries (voluntarily) report forest-related fluxes and are expected to do so consistent with GHGIs. These new requirements are driving the use by developing countries of the 2003 GPG for LULUCF.

The main difference between the 1996 Guidelines and the 2003 GPG is that the 2003 GPG requires the identification and tracking of the use, and change in use, of different types of land (forest land, grassland, cropland, settlements, wetlands and other lands) across time. In the 2003 GPG, area data are the basis of most methods applied to estimate C stocks and C stock changes. Difficulties stem from the need to collect time-series data across the entire country, including in remote areas, and in inferring the use of land from information that mostly refer to the land cover elements (see Section 3.3.1). The identification and tracking of land use and change is referred to as “land representation”, whose consistency across the GHGI time series is key to ensure accuracy of GHG estimates. The concept of land use also embeds the concept of the “managed land proxy” (see Section 2.2).

The 2006 IPCC Guidelines fully incorporate the methodological approaches of the 2003 GPG. The main difference is in the treatment of CO_2 emissions from forest fires. The 2003 GPGs allows an assumption that such emissions balance out over time with CO_2 removals from forest regrowth, while in the 2006 Guidelines both emissions and removals from such disturbances need to be reported. Further, the IPCC has released two supplements to the 2006 Guidelines that may be voluntarily applied:

- The Kyoto Protocol (KP) Supplement[32], that includes a methodological refinement on the implementation of the managed land proxy, aimed at singling out (on a voluntary basis, for accounting purposes) the emissions and subsequent removals associated with extraordinary occurrences of natural disturbances. It also provides guidance to deal with inter-annual variability of non-activity related parameters;
- The Wetlands Supplement, that provides additional methods for estimating GHG fluxes from organic soils and coastal ecosystems, including mangroves forests.

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[30] The IPCC 1996 Guidelines includes the following categories: 5A Change in Forest and Other Woody Biomass Stocks (which includes F→F or NF→F, although limited to forest plantations, as well as emissions and removals from other wooded lands that do not meet the forest definition); 5B Forest and Grassland Conversion (which may be assumed to be dominated by deforestation); 5C Abandonment of Managed Land (which may reflect more or less anthropogenic NF→F, also as natural forest expansion on previously managed lands).
[31] UNFCCC, Decision 2/CP.17, Annex III, paragraph 5-6.
[32] The KP Supplement provides methodological guidance for estimations by Annex I Parties for the second commitment period of the KP.

Forest degradation is complex to define[33]. In the context of GHG flux estimation (Thompson et al, 2013), it is often understood (and estimated) to be a decrease in carbon stocks in forests across time without a corresponding land use change; for example, conversion of primary forest to secondary forest[34]. Forest degradation may also occur if there is a net decline in long-term average carbon stocks due to an increase in wood removals in managed (secondary or planted) forest. It may be a significant source of net emissions, particularly in developing countries[35], but is not always well estimated or reported in GHGIs.

Even though it may appear that countries report degradation within "forests remaining forests" (per Table 5), many developing countries do not have sufficient data to provide robust estimates of the actual net C stock balance of forest land, and consequently on whether processes leading to long-term decline in carbon stocks are occurring in forest land. Many developed countries have repeated national forest inventory (NFI) cycles using consistent methodologies that allow for quantified estimates of net decreases across time of carbon stocks in forest land. However, many developing countries do not conduct repeated NFIs (or successive NFIs are implemented with external technical support and different methodological approaches), and therefore consistent data are unavailable. Such time series data are useful to estimate forest degradation, particularly in the cases where a country does not have adequate management data which also can be used to estimate emissions from degradation, e.g. legal and illegal logging rates and changes in such rates.

Reducing emissions from forest degradation is a REDD+ activity but is less widely covered than deforestation in forest reference emission levels (FRELs) submitted so far. For example, while Brazil, Paraguay and Peru reported on the F→F category in their respective national GHGIs, in their FREL submission (see box below), these countries currently exclude degradation, suggesting they are currently unable to provide what they consider to be sufficiently robust estimates of historical or actual degradation at this time[36], including separating out forest management practices that do not qualify as degradation. A number of countries are beginning to experiment with different options to measure net emissions from degradation, typically using high resolution remote sensing imagery or proxies based on drivers, but this remains an emerging field[37]—driven in large part by countries pursuing REDD+.

Unless a robust monitoring system is in place (e.g. plot systems), countries' GHGIs also often miss carbon removals from forest regrowth[38]. Per unit area, forest regrowth has much slower impact on the annual carbon balance than deforestation or most kinds of forest degradation and, perhaps for this reason, has been less of a focus in GHGI design. However, while forests regrow gradually, possibly over many years, the accumulated removals of the total area regenerating at any time may be significant[39].

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[33] IPCC (2003), *Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types*. (http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation.html); GFOI (2016), Methods & Guidance Documentation. (https://www.reddcompass.org/download-the-mgd)

[34] Primary forests are naturally regenerated forests of native species where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Where there are clear visible indications of human activities, naturally regenerating forests are considered secondary forests. Secondary forests have a long run average C stock lower than primary forests.

[35] FAO FRA shows that degradation (defined as a net C stock loss across a 5-year period) largely occurs in developing countries.

[36] Many countries are working on methods to estimate emissions from degradation. For example, Brazil's GTT REDD+ is advancing a forest degradation concept for Amazonia, linked to recurrence of events as a single selective logging or fire event may not be associated with forest degradation; the definition by Brazil will consider the permanent loss of the functions forests play.

[37] In 2014, GFOI, GOFC-GOLD and ESA held a workshop on approaches to monitoring forest degradation for REDD+ that reviewed the techniques available, see http://www.gfoi.org/wp-content/uploads/2015/03/GFOI-GOFCGOLD_RDExpertWS2_Report.pdf

[38] Throughout the paper the term "regrowth" refers to both carbon accumulation in F→F and NF→F.

[39] Furthermore, the rates of CO2 accumulation may be quite high in the initial decade or two of regrowth, e.g. Poorter et al (2015), Biomass resilience of Neotropical secondary forests, Nature 530, 211-214; also, the area covered may be very large, as illustrated by Brazil's TerraClass data on regrowth of deforested areas in the Amazon (http://www.inpe.br/cra/projetos_pesquisas/terraclass2014.php).

The context of REDD+ reference levels

According to decisions by the COP, countries may voluntarily submit “forest reference emission levels or forest reference levels” (FRELs), which contain national estimates of forest-related GHG fluxes. The requirements of FREL submissions differ than those of GHGIs. Whereas a country, following IPCC guidelines, should submit a complete inventory of emissions and removals, the focus of FRELs is to include *significant* pools and activities. Countries may also take a stepwise approach to developing FRELs, incorporating additional pools over time. At the same time, COP decisions state that FRELs should maintain consistency with forest-related emissions and removals contained in national GHGIs.

The purpose of FRELs also differs from that of GHGIs. Nearly all FREL submissions state that the information is provided “in the context of results-based payments”. Because of this context, the scope of the submissions tends to be narrower than the data and information provided in national GHGIs, often because there is an expectation that results-based payments will require more accurate estimates. Therefore, activities with less data or greater uncertainty (e.g. forest degradation and regrowth) are often not included in FRELs.

Developed country reporting on removals from forests tends to be more complete than developing countries. This may be due to the fact that Annex I countries have been reporting regularly since 1996, but also because those with Kyoto Protocol obligations had an incentive to estimate removals which could be used to help achieve their “target”. The lack of information and knowledge on carbon removals from forests is, perhaps, best illustrated by submissions of REDD+ FRELs to date. The majority focus exclusively on deforestation, and most only estimate gross loss of forest cover, due to a lack of knowledge on the post-conversion land use type and/or C stock. While one-third of the submissions attempt to include a portion of F→F (i.e. forest degradation, largely focused on estimating gross carbon loss from timber harvesting), few attempt to estimate the removals from growth (F→F, 3 countries) or regrowth (NF→F, 9 countries). Ignoring regrowth may overestimate the net emissions that result from forest cover loss by classifying all cleared lands as deforested (i.e. with permanent loss of forest cover). In most countries, at least some cleared areas are eventually fallowed, enabling forest regrowth.

2.4.2. Reporting on C Pools

Another reason countries may not report forest-related emissions and removals completely in their national GHGIs is the lack of data for certain carbon pools. IPCC Guidelines require national GHGIs to report on significant emissions or removals associated with five pools: aboveground biomass (AGB), belowground biomass (BGB), deadwood (DW), litter (L)40, and soil organic matter (SOM). Harvested wood products (HWP) compose an additional, man-made, sixth pool. National reporting and independent studies normally include biomass pools; other pools are included to varying degrees. The IPCC Guidelines provide methods to estimate all pools, including default factors41, and therefore enables country reporting for all pools. However, in practice not all countries report comprehensively (see Table 6). Especially for developing countries that do not have regular NFI cycles, the data on some pools may be old or non-existent. The net C stock change of deadwood, litter, and soil, in particular, is often assumed to be insignificant or, consistent with methodologies in IPCC Guidelines (at Tier 1 level), such pools may be assumed to have across time no net C stock changes (i.e. zero net-emissions) in F→F.

[40] Dead wood and litter are often grouped together into a C pool called dead organic matter (DOM).
[41] Noting that under default assumptions DOM and SOM in mineral soils are assumed not to change for forest remaining forest.

Table 6: Coverage of pools in national GHGI reporting, based on country reports to UNFCCC

Figures in parenthesis are approximate because the pools included are often not explicitly specified.

		Carbon pools			
		Biomass (above- and below-ground)	Dead organic matter (dead wood and litter)	Soil carbon	
				Mineral soil	Organic soil[2]
Annex 1 countries[1] (41)	F→F	41	25	18	17
	NF→F	37	26	32	15
	F→NF	35	32	33	11
≈ top 20 forest Non-Annex 1		20	(3)	(7)	(2)

[1] Annex I excluding Malta (with negligible forest) and Monaco (with no forest).
[2] Reported with actual numbers. Many countries do not have organic soils.

Coverage of pools is more complete for Annex I countries. The lower coverage of mineral soil in F→F reflects the difficulty to estimate detectable soil C stock changes in this category. Organic soils are less reported than other pools because significant areas with organic soils may not exist in some countries. For non-Annex 1 countries, the situation is much less certain—beyond biomass, it is often unclear which pools are included. Based on information collected, most non-Annex 1 countries do not report non-biomass pools.

Harvested wood products (HWP) are now reported by the vast majority of Annex I countries, using IPCC default or country-specific decay rates[42]. By contrast, all non-Annex I countries apply a default assumption that all carbon biomass harvested is oxidized in the removal (harvest) year[43].

The Table below summarizes the potential impact of excluded pools on deforestation (F→NF) flux estimates compared to the case where only AGB is estimated.

Table 7: Maximum potential scale of C stock losses in missing carbon pools compared to C stock losses from the aboveground biomass ABG pool for deforestation emissions estimates

Missing pool	Potential impact on estimate	Comment
BGB	From 20 to 55% of ABG biomass	If the full carbon content of BGB is assumed to be released to the atmosphere with deforestation, IPCC root-to-shoot ratios suggest that the resulting estimated emissions could increase by 20% to 55% depending on the ecosystem—for tropical rain forests a representative value for the root-to shoot ratio is 0.37, and tropical dry forests, can have a value as high as 0.56.
DW and L	From 15 to 100% of ABG biomass	C stocks in DW and L in boreal forests can be of the same magnitude as AGB C stock[44], and may be released to the atmosphere similarly to AGB depending on the type of disturbance. In temperate and tropical forests, the importance of DW and L is smaller and could be around 15% (Brown et al, 1992).

[42] Most Annex I countries use the production (vs. consumption) approach to reporting HWP, thus avoiding gaps or duplication. For more information see: http://www.climateandlandusealliance.org/reports/understanding-land-use-in-the-unfccc/
[43] 1996 IPCC Guidelines, Vol. III, page 5.17, Box 5.
[44] Using the Canadian CBM-CFS3 model this is more or less the result from Zamolodchikov et al (2013).

SOM in mineral soils	Large variability (however, according to IPCC default methods it may be ~10% across the entire conversion process[45])	There is a need for more consistent data on C stocks of soils, and on soil carbon stock *changes* with land use transitions and with changes in management systems. In Annex I countries, mineral soils represent on average about 5-10% of the total flux in the various forest categories, but this contribution varies considerably among countries and is larger in tropical countries.
SOM in organic soils	From 30-40[46]% of ABG biomass (or higher for tropical peat forest)	Emissions/removals from organic soils occur across long time periods, so that their exclusion may have a relatively small impact on the annual[47] GHG balance of a specific unit of land deforested. Impact could be even higher than the range provided in tropical moist deep drained land, particularly if followed by fire[48].

2.4.3. Reporting on gases

National GHG inventories are required to include all GHGs. CO_2 emissions account for the majority of forest-related GHG emissions, while non-CO_2 gasses frequently represent a small fraction of the total. The main source of non-CO_2 forest emissions is fire[49] (CH_4 and N_2O) and the loss of soil organic matter (N_2O).

In Annex I countries, where the reporting of forest fires may be considered complete for the vast majority of countries, non-CO_2 fire emissions represent about 10-12% of total CO_2-equivalent fire emissions (including biomass burned). Relative to the total forest fluxes, non-CO_2 emissions represent about 2-3% of total CO_2-equivalent forest sink, with country differences mainly explained by the relative importance of fires.

In non-Annex 1 countries the situation regarding non-CO_2 fluxes is less clear. The vast majority of countries do not report specific information on non-CO_2 gases, and in this case it can be assumed that only CO_2 is reported from fire (e.g. fire often occurs as part of a land use change, e.g. F→NF, and therefore CO_2 emission are already included in the loss in biomass reported). Only a few countries (including Brazil, India, Indonesia, DRC) explicitly include non-CO_2 emission from fires, although for the same country the coverage sometimes differs for different reports, e.g. Brazil reports all GHGs in its National Communication, but only CO_2 in its FREL (that includes only the activity of reducing deforestation[50]) and REDD+ BUR annex. Indonesia reports all GHGs in the 2nd National Communication, but only CO_2 in the BUR and its FREL. The relative importance of non-CO_2 emissions related to forests may differ in developing countries compared to Annex I countries, particularly those countries that experience peatland fires (and where such fires occur on lands within the forest land use category).

[45] IPCC default establishes a conversion period of 20 years.
[46] Calculated summing up annual net GHG fluxes reported in Chapter 2 of the 2013 IPCC Wetlands Supplements for Boreal and Tropical forests and compared to the ABG stock reported for boreal and tropical forest in table 4.12 of Volume 4 of the 2006 IPCC Guidelines
[47] However, across time and across the entire country, depending on the total area of forested and deforested land drained, the GHG flux may be an order of magnitude larger than that of the AGB.
[48] E.g. if a peat swamp forest is converted to an oil palm plantation then drained, the emission factor for such drainage is ~55 tCO2/ha/yr, which would continue for multiple years after the land use change (as long as peat stays drained, compared to a one-time emission of ABG counted in year of clearing under Tier 1). Then, if followed by burning, the emission factor for burning tropical peat is ~800 tCO2e/ha, so combined with peat drainage, could be far higher than >100% of ABG biomass assuming an average ABG stock of 100 tC/ha (367 tCO2/ha emission).
[49] In the case of fuelwood, carbon stored in biomass is reported as harvest loss and non-CO_2 gases from burning are reported under energy in the GHGI. It should be noted that the estimation of emissions from fire may vary considerably depending on assumptions used in estimating burnt area, including fraction of biomass burned. When emissions from fire include peat, the complexity increases in term of assumptions used in estimating depth of peat burned.
[50] Including non-CO_2 emissions from fire in a FREL is complicated when a country is limiting emissions to, e.g. the REDD+ activity of deforestation, as fire-related emissions may result in degradation; to include non-CO_2 gases in this instance would require knowledge of the amount of deforestation caused by fire. Brazil's FREL submission pre-dated its 3rd NC, where it separates emissions from fire on deforested areas.

2.4.4. Other processes that may not be fully reflected in GHGIs

There may be other carbon stock change processes that are not entirely included, or not included at all, in national GHGI reports. Below are short summaries of these potential additional gaps that may occur in national reporting, and why they may be missing from national estimates of forest fluxes. Not all are required estimates for national GHGIs (see Table 8). Whether or not they are included, however, can impact how GHGI estimates compare with independent studies, or help to explain discrepancies.

Legacy effects: The term legacy refers to emissions/removals (CO_2, and N_2O for SOM) occurring in years subsequent to a disturbance that has caused an abrupt change in C stocks (e.g. accumulation of dead organic matter due to pest, or of HWP due to harvesting) or a change in the management/disturbance regime that determines an increase of the long run average C stock (e.g. by extending the harvesting cycle) of the forest or in its long-term decrease (e.g. by shortening the harvesting cycle). Legacy emissions/removals would be constant across time under assumptions of a constant level of management and background level of disturbance. In these cases, estimating emissions by assuming instantaneous oxidation of C losses would yield the same annual emissions/removals as explicit consideration of legacy effects. However, in practice these assumptions are unlikely to occur and legacy effects will need to be taken into account to estimate emissions, removals and carbon stocks over a given time period, since these may differ significantly from the long run average. Legacy emissions are likely to be more relevant in forests where decay and accumulation processes are slower, as in boreal forests.

Long time series of data (as long as the effect of the disturbance or of the change in management or disturbance regime) are needed to properly estimate legacy emissions/removals. For this reason, many Annex I Parties' GHGIs are prepared from datasets that contain data as far back as the 1970s. The relative shortage of historical data in developing countries makes a proper quantification of legacy emissions/removals challenging and may have an impact on the level, and possibly also on the trends, of reported GHG emissions/removals.

Age class structure: Age class is a type of legacy effect. It refers to the case when disturbances or management at the landscape or stand level cause an abrupt loss of biomass (and corresponding accumulation of C stocks in the dead organic matter pools including HWPs which then decay) followed by the rejuvenation of groups of trees about the same age. If left undisturbed, the original landscape equilibrium will eventually be re-established; however, there will for some time be a perturbation in the level of stocks and emissions/removals. If the forest is repeatedly harvested, it may never reach the original equilibrium average level of carbon storage. Assumptions made about age class effects on GHG fluxes, or the methodology used to calculate the C stock changes (e.g. constant factors *versus* the use of models that calculate C stock changes on the basis of annual data inputs) can result in significant differences in annual estimates of emissions and removals, particularly in terms of timing—when fluxes actually occur versus when they would be reported, and also in terms of total amount if conditions change over time. In general, developed country GHGIs largely capture the impacts of age class, whereas many GHGIs of developing countries do not. Global studies tend not to consider, or not fully consider, the impact of age class distribution because of the current absence of a global dataset[51].

[51] The Hansen et al. (2013) dataset, visualized on the Global Forest Watch (GFW) web platform, may in the future provide relevant data when the time series is long enough to reconstruct tree cover removal and regrowth dynamics of forest land.

The Use of Tier 3 Methods

As defined by the IPCC Guidelines, Tier 3 methodological levels use higher order methods, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. Pieces of land where a land-use change occurs can usually be tracked over time, at least statistically. In most cases these systems have a climate dependency, and thus provide source estimates with interannual variability.

Such higher order methods can provide estimates of greater certainty than lower tiers—if they are suitable for the forest typologies and their associated management, and their outputs verified. There can be high variability on how such models are constructed and what inputs are used, and therefore may vary country by country and with independent studies.

CO_2 fertilization effect: Increasing atmospheric CO_2 may increase terrestrial C uptake as long as there is adequate supply of water and nutrients, and possibly long run C stocks, but the magnitude and the spatial distribution of these impacts are still debated (Korner et al, 2007; Morgan et al, 2004). Although modelling estimates have to be taken with care, Ciais et al (2005) using a combination of biogeochemical modeling, atmospheric measurements and forest inventories estimate that CO_2 fertilization could explain as much as 100% of the biospheric tropical sink which, with large uncertainties, is of similar magnitude as emissions from deforestation, or 1–2 GtC/yr. Recent publications (Schimel et al, 2015; Keenan et al, 2016) associated the observed increases in the terrestrial sink during the past decade mainly to the effects of rising atmospheric CO_2 on vegetation. On the other hand, studies on long CO_2 fertilization confirmed in 18 unimpaired tropical rainforest catchments that increasing concentration of atmospheric CO_2 was a minor contributor to dryland productivity trends (Brant et al, 2017), yet was the main variable driving the growth of woody vegetation in humid areas, enhancing primary production (Yang et al, 2016). National inventory reports which use a stock-difference method (i.e. comparing direct measurements of forest carbon stock from two different points in time) inherently include fertilization effects. Other national GHGI reports use standardized yield tables that may not fully include[52] the impact of CO_2 fertilization, thereby potentially underestimating CO_2 fertilization effects on growth, while others may use models that may include or not CO_2 fertilization effects. In general, however, it may be assumed that many national GHGIs include CO_2 fertilization effects. On the other hand, many scientific studies (e.g. Houghton et al 2012a) aim to estimate the direct human-induced impact only, therefore excluding CO_2 fertilization effects.

Overall, although the impact of CO_2 fertilization is still subject to scientific uncertainties, it may be potentially relevant. Therefore, the extent to which it is included in GHG estimates may represent a potentially important reason of the differences between country reports and scientific studies.

Nitrogen (N) deposition effects: Improved N bio-availability after deposition of atmospheric N, on its own and interactively with the CO_2 fertilization effect, is an important C sink process in N-limited regions. This N originates from the combustion of fossil fuels, biomass burning or from the volatilization of N from organic or inorganic sources in agricultural N fertilization. The impacts of N fertilization on forests from deposition is probably most important in Europe and the Eastern United States because of the large

[52] E.g., if a single yield table representative of the year 2000 is used for the entire time series 1990-2015, the impact of CO_2 (and other climate-induced effects) is partly included in the level of GHG estimates (i.e. the impact occurring in the year 2000) but not on the trend of GHG estimates from 1990 to 2015.

quantities of N emissions and because many of those forests are N limited (Canadell et al, 2007). Globally, N deposition may have accounted for about -0.19 to -0.25 GtC/yr of the -0.2 to -1.4 GtC/yr net terrestrial C sink during the 1980s and 1990s (Nadelhoffer, 1999; Sabine et al, 2004). A recent study that modelled fluxes at 68 forest sites estimated that 19% (+/- 29%) of the observed increases in C sink were due to N deposition effects on biomass, with larger effects in temperate and tropical forest (Fleischer, 2015). In the future, further enhancement of the terrestrial C sink will probably not stem from N fertilization because of the expected larger future growth of the CO_2 forcing effect (some models indicate that temperature effects are likely to overwhelm effects of increased N deposition; Bala et al, 2013) and the negative effects on additional N deposition in regions already N saturated (Canadell et al, 2007).

Permafrost thaw: There is little quantified information on the occurrence of permafrost thaw *in forest land* as distinct from all lands, making it difficult to estimate the scale of this process for just forests. That said, recently Potapov et al (2017) estimated that almost 52% of the total permafrost area within forest zones in North America and Eurasia is located within remaining intact forest landscapes, largely within areas designated as unmanaged in national GHGIs. With regard to land in general (some of which will include forest land), studies suggest the northern permafrost zone contains anywhere from around 1,500 to 1,700 Gt of carbon (Schaefer et al, 2012), one-fifth of which is in peatlands (Swindles et al, 2015). However, while the IPCC's 5th Assessment Report[53] states that there is *high confidence* that warming is causing reductions in permafrost extent there is *low confidence* on the magnitude of carbon losses. Schaefer et al (2012) estimate that thawing permafrost could emit 43 to 135 $GtCO_2e$ by 2100, and 246 to 415 $GtCO_2e$ by 2200 (as CO_2 and methane emissions). While academic literature suggests a gradual and prolonged release of GHG emissions from permafrost *soils* in a warming climate, permafrost carbon dynamics are poorly understood (Schuur et al, 2015). The literature is unclear on whether the Arctic is a net sink or source—on one hand the loss of sea ice, decomposing permafrost and increasing tundra fires increases emissions while potential photosynthetic activity (i.e. new Arctic vegetation and longer growing season; Parmenier et al, 2013) and peat accumulation increase CO_2 removals in a warming climate (Charman et al, 2015).

Black carbon: Combustion products from vegetation fires such as char, ash, soot and charcoal are commonly referred to as black carbon (BC), and are all resistant to further biological or chemical decay. Hence, BC has a significant half-life, in the order of thousands of years and is thus the most stable biomass-derived material in the biospheric C cycle. It tends to accumulate in soils and other terrestrial and marine sediments and to act as a removal (sink) of carbon from the more rapid bio-atmospheric carbon cycle to the slower (long-term) geological carbon cycle (Graetz and Skjemstad, 2003; Schmidt, M.W. I, 2004; Druffel, E.R.M, 2004). Forbes et al in 2006 estimated that 4-5% of biomass burnt in forest fires was converted to BC, with total BC from forest fire estimated to be 0.56 to 0.74 Mt C[54]/yr (Bond et al, 2013). BC comprises up to 40% of the organic C in terrestrial soils and 12-31% of the very large pool of organic C in deep ocean sediments (further, radiocarbon ages of BC in soils is in excess of thousands of years)[55]. The key question determining whether BC is an important component of forest net fluxes is whether the rate of annual BC formation exceeds the annual amount of C released from the large pool of BC that is already accumulated in terrestrial and marine ecosystems. These carbon storage attributes

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[53] IPCC 5th Assessment Report, *Could Rapid Release of Methane and CO_2 from Thawing Permafrost or Ocean Warming Substantially Increase Warming?* WG I, Chapter 6, section 6.4.3.4 (page 526) and FAQ 6.1.
[54] C fraction of around 0.6 according to James S. Clark and Helene Cachier (2013), *Sediment Records of Biomass Burning and Global Change*, Nato ASI Subseries I.
[55] 2006 IPCC Guidelines, Vol. 4, Appendix I: CO_2 Removals in Residual Combustion Products (charcoal): Basis for Future Methodological Development.

may be partially offset by a potentially significant effect on radiative forcing and albedo[56] which could contribute to warming effects.

Natural disturbances: Although the impact of natural disturbances on the GHG balance in managed land may be assumed to average out across long time periods under constant environmental conditions, annually they can cause large variations in the anthropogenic GHG balance of a country. The IPCC Guidelines are that countries apply the managed land proxy (as described in Section 2.2), which would therefore include emissions and subsequent removals associated with natural disturbances on managed land in national GHGI *reporting.* However, when assessing performance relative to a national target (*accounting*), countries may wish under certain circumstances to, in addition to applying the managed land proxy, exclude a portion of emissions and subsequent removals associated with extraordinary occurrences of natural 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. An approach to do this was agreed under the Kyoto Protocol for Parties to use during the second commitment period, along with a requirement (for transparency) that countries would still report disturbance emissions in their national GHGI. The Kyoto rules also require evidence of actions taken to limit such disturbance events, and disallow exclusion of emissions if the disturbance is followed by land-use change. While the Paris Agreement has not yet established any specific rules or guidance on how countries may account for natural disturbances in the achievement of their NDC, it recognizes that existing methods and guidance should be taken into account[57].

[56] Ibid.
[57] Article 4, para 14 of the Paris Agreement.

Table 8: Potential impact of various processes that can impact the comparability of forest flux estimates

Process and potential impact on quantified estimate	Inclusion in GHGI		Comment
Legacy	Expected to be included in GHGIs	The IPCC provides default methods that include the impact of legacy effect for estimating C stock changes in: • the biomass C pool, as age class effect, and in the HWP pool of F→F • in all C pools in NF→F and F→NF.	Not considering legacy effects may result in either over- or under-estimating fluxes in a given reporting year; the time-averaged magnitude of impact likely declines when fluxes are considered over longer periods (which require long time series of historical data). Legacy fluxes are likely to be more relevant in forest where decay and accumulation processes are slower, as in the boreal forest.
Age class 10%-40%[58] of net C stock change in F→F	Expected to be included in GHGIs	Age class structure, or a similar independent variable to estimate C stock change rates as a function of C stocks, is expected to be included in GHGI estimates. It is included in the IPCC default method for estimating C stocks and C stock changes in the biomass C pool in F→F, NF→F and in F→NF.	Not considering the age class of forests may result in either an underestimate or an overestimate of the true C stock change value.
CO_2 fertilization At global scale, 1-2 GtC/yr	Expected to be included in GHGIs	CO_2 fertilization is theory implicitly included in the IPCC default methods for estimating C stock changes in F→F, NF→F and F→NF, although the use of IPCC default factors may not fully reflect its impact.	Several studies suggest CO_2 fertilization as a likely, dominant explanation of the global enhancement of the terrestrial sink, although It varies among biomes. However, there are still considerable scientific uncertainties, e.g. due to contrasting results from CO_2-enrichment experiments and uncertainties associated with data and modeling results.
N deposition Estimates highly uncertain ~0.2 GtC/yr (or around 19% of the C sink)	Expected to be included in GHGIs	N deposition effect is implicitly included in the IPCC default methods for estimating C stock changes in F→F, NF→F and F→NF, although the use of IPCC default factors may not fully reflect its impact.	Nitrogen fertilization is probably most important in Europe and the Eastern U.S. because of the large quantities of N deposition and because these forests are in N limited conditions.
Permafrost thaw Unknown in forested lands	Not expected in GHGIs	Although IPCC methods do not exclude reporting its effect, current monitoring systems do not include data collection on permafrost thaw and on its impacts on GHG fluxes in F→F, NF→F and F→NF.	There is high uncertainty of emissions from permafrost thaw and no estimates for permafrost in only forested areas.
Black carbon	Not expected in GHGIs	IPCC methods do not estimate C accumulation as black carbon and its subsequent decay. All carbon contained in fuels of combustion processes is assumed to be instantaneously emitted as CO_2, including organic matter combustion in F→F, NF→F and F→NF.	Annual production from forest fires around 0.9 – 1.2 Mt BC, high uncertainty on annual emissions from BC oxidation.
Natural disturbance Ideally in equilibrium across time, although may be significant in a given reporting year	Special case	Emissions and subsequent removals associated with natural disturbances in managed land are expected to be included in GHGI estimates.	While natural disturbances may have a significant impact on forest-related fluxes in any given year, these effects should average out across time.[59]

[58] Range of variation of net increment across a 24-year time series of the UK GHGI (10%) and Russian GHGI (40%) using a predictive model based on age class distribution and yield curves (UK) or chrono-sequences (Russia).

[59] The exclusion from accounting of emissions associated with natural disturbances should be balanced by the exclusion of subsequent removals (on lands where the disturbance took place). However, non-CO_2 emissions (e.g. from fire) would be permanently excluded from the accounting. Furthermore, if there is an intensification of the natural disturbances regime, excluding subsequent CO_2 removals would not entirely balance out CO_2 emissions.

2.5. Summary of what's in (and what's out) of GHGIs

The purpose of GHGIs is to report information on anthropogenic emissions and removals within national boundaries. To achieve this, countries estimate emissions and removals following the methodological guidance that IPCC has been producing from 1995 onwards and the UNFCCC's reporting guidelines. Countries' have committed to include all anthropogenic emissions and removals in their reports, which is part of the total flux to and from the atmosphere within the national boundary.

What is included in national GHGIs

If a country follows IPCC Guidelines, all GHG emissions and removals associated with net C stock changes in all C pools on managed forest lands should be estimated and reported. This includes forest growth and biomass turnover and mortality, harvesting and fuelwood collection, natural disturbances (e.g. fires and pest), accumulation and decay of dead organic matter and soil organic matter, production and decay of wood products and emissions and removals from drained and rewetted organic soils. At Tier 1 reporting, changes in dead wood, litter and organic carbon in mineral soil pools in forest remaining forest60 are estimated as zero (i.e. equilibrium of emissions and removals is assumed). The net emissions and removals of CO_2, and categories of CH4 and N2O associated with net C stock changes are reported and summed up to the national total of anthropogenic net emissions. Important sources of uncertainties are related to what can be considered directly human induced within F→F and to the identification and quantification of the complex forest dynamics beyond deforestation.

What may not be included in national GHGIs

As discussed above, GHG fluxes that occur on unmanaged lands (and therefore assumed not to be a result of an anthropogenic activity) are not reported in GHGIs. For managed lands, national reports vary in both quality and completeness, with some pools and gases reported less comprehensively than others. In forests, above and below ground biomass are the most likely pools to be included, others less so. The Table below is the authors' best estimate of the most significant anthropogenic emissions and removals that may not be included in the current status of development of counties GHGIs.

Some other fluxes may also be significant, including:

- Impact of permafrost thaw;
- N_2O emissions from mineralization of soil organic matter where not associated with a net SOC change;
- CH_4 emissions from termites and from ruminants, where not part of husbandry systems[61];
- Net C stock accumulation in the black carbon pool originating from fires in managed and unmanaged lands.[62]

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 independent studies.

[60] These pools are assumed to remain constant at Tier 1. Default values are provided to estimate emissions associated with transition to other land uses.

[61] Climate science of methane, at: http://www.eci.ox.ac.uk/research/energy/downloads/methaneuk/chapter02.pdf

[62] Kuhlbusch, T. A. J., and P. J. Crutzen (1995), T*oward a global estimate of black carbon in residues of vegetation fires representing a sink of atmospheric* CO_2 *and a source of O2*, Global Biogeochem. Cycles, 9(4), 491–501, doi:10.1029/95GB02742. Sink estimated in the order of 0.05-0.27 GtC/yr.

Table 9: Discrepancies between actual GHG forest fluxes and those reported in GHGIs

(separated by those that should be included in current[63] national GHGIs, but are assessed by authors to be gaps in reporting, and those which are not required in GHGIs)

GHG fluxes that should be reported in GHGIs (using IPCC guidelines)	GHG fluxes that are not required in GHGIs
• Non-living biomass pools (SOC, DW, L) assumed constant (per use of Tier 1 methods) in forest remaining forest. These pools should be estimated at Tier 1 in land conversions from and to Forest, and at higher Tiers for forest remaining forest. • Emissions/removals from drained/rewetted organic soils—more likely to be included than previously, following publication of IPCC's 2013 Wetland Supplement • Managed lands for which not enough data yet exist to estimate GHG emissions and removals (especially in developing countries) • Removals from managed primary forests that are either not estimated or improperly estimated • CO_2 and N fertilization in managed lands, if yield tables or growth models are used that do not incorporate these effects. • Emissions/removals associated with other climate change impacts, such as longer growing seasons, higher temperatures and different precipitation patterns (including extreme events) that may not be captured by some methods of GHG estimation. • All emissions and subsequent removals associated with natural disturbances on managed land, including those which are out of human control (although the latter may be excluded when *accounting* for mitigation)	• Perturbations of the C stock equilibrium in unmanaged forest land due to changes in the natural disturbances regime associated with climate change • The natural sink in unmanaged peatlands forest • CO_2 and N fertilization in unmanaged forest lands • GHG from fires on unmanaged forest land

[63] The table is based on the current status of GHGIs; however, as explained in the text, these are expected to improve over time and, as such, the assessment may change in the future.

3. Comparing national GHGI reporting to independent studies

3.1. The context of independent studies

Independent studies of carbon fluxes from forests and land are published by somewhat distinct research communities using three different approaches: top-down atmospheric models, bottom-up terrestrial biosphere models, and estimates of GHG fluxes from data/observations on land use or land cover change combined with carbon stock estimates (reported by countries or in literature). These studies are often not directly comparable with country reporting to the UNFCCC, nor among themselves, although in some cases comparability may be increased by looking at the disaggregated components of the estimates. While we call such studies independent, they may sometimes use national reporting data or the same underlying national forest inventory (NFI) data that many national GHGIs rely upon; similarly, national reporting may use information from scientific studies (i.e. emission factors).

There are other differences between independent studies and national GHGI reporting. Often the aim of independent studies is to publish new results, whereas national GHGIs aim to provide consistent time-series data with each report. Requirements differ as well—for example, international reporting must follow internationally agreed methodologies, and national reports need take into account national decisions (e.g. that define forests or land use, which may affect the allocation of emissions and removals between forest and non-forest categories). Independent studies may also adopt different forest definitions and may not align with national distinctions or definitions such as anthropogenic versus non-anthropogenic GHG fluxes. Independent studies and national GHGI reporting are all subject to peer review, although the review process differs[64]. There may also be differences in the processes analyzed, the spatial and temporal scale of the analysis, data access and technical expertise. These differences cumulatively help explain why a variety of approaches are applied, resulting in a range of estimates of GHG fluxes between forests and the atmosphere.

IPCC AR5 vs. country GHGI reporting

The objective of the IPCC's Assessment Report (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, what this report refers to as "independent research/studies", for its *global* assessment of the physical science basis of climate change (Working Group I) and to inform its portfolio of options for mitigating climate change (Working Group III). The IPCC's Task Force on National GHG Inventories (TFI) was established to develop internationally agreed methodologies to estimate *national* GHG emissions and removals. These different objectives have led to differences among the data, information, and methodologies used in the assessments made by the IPCC's AR process as compared to the IPCC Guidelines developed by the TFI and used by national governments to report national GHGIs to the UNFCCC.

[64] Independent research papers may be rejected because of review outcomes and the analysis provided by the reviewers is not published. Information reported to the UNFCCC is never rejected and the complete analysis made by reviewers is published. Consistency of information submitted to the UNFCCC with other national datasets is a relevant issue for GHGI review that is not generally taken into consideration in the review of independent studies.

The main difference between methods used to estimate forest net emissions included in IPCC Assessment Reports and those in country reporting to the UNFCCC is the treatment of anthropogenic emissions and removals (other differences are covered in Section 3.3). In country reporting, it is necessary to separate anthropogenic emissions and removals form non-anthropogenic fluxes, as countries commitments are in relation to anthropogenic fluxes only. As explained in Section 2.2, the IPCC Guidelines for National GHGIs apply the concept of *managed land* as a *proxy for anthropogenic effects* (both direct and indirect effects) for the land use sector, with the assumption that the preponderance of anthropogenic effects occurs on managed lands. Areas of land considered "managed" are defined by national governments (subject to IPCC guidance[65]), with each land use disaggregated between "land converted to other land uses" (e.g. L→F, typically in the last 20 years) and "land remaining under the same land use" (e.g. F→F). Estimates from global modeling approaches, such as those used in IPCC AR5 (Ciais et al, 2013, which draws from, e.g. Houghton et al, 2012a) and the Global Carbon Project (Le Quéré et al, 2015), are based on a wide range of data sources and take a different approach to separate management effects (i.e. direct effects) from indirect (or natural) impacts, and include different processes, definitions, and approaches to calculate global emissions and removals from forests. IPCC's AR5 distinguishes between emissions and removals resulting from:

1. Land use change* including fluxes based on changes in land cover (over a longer time period than that used by GHGIs as a default to distinguish between "land converted to other land uses" and "land remaining in a land use"). For instance, the Houghton bookkeeping approach (Houghton et al, 2012a) estimates anthropogenic effects by tracking the CO_2 emitted to the atmosphere during and following specific management interventions, for example during deforestation, and over time due to the follow-up decay of soil and vegetation carbon in different pools, including wood product pools. Depending on the modeling capability, some forms of forest management such as wood harvest, shifting cultivation and forest regrowth may also be included in estimates of GHG fluxes. Houghton et al considers degradation of forests (where a fraction of trees is removed) and forest management (wood harvest with replanting), and also tracks the regrowth of vegetation and associated build-up of soil carbon pools after land-use change. The activity data underlying these estimates is derived from country reports to the FAO's Forest Resource Assessment (FRA), and include net land use changes in all forest and land areas rather than gross land use changes on "managed land", as per methods provided by IPCC Guidelines.

2. The "residual terrestrial sink" is estimated by the difference of the other terms of the global carbon budget (i.e. the total net CO_2 flux between the land and atmosphere minus CO_2 flux from land use changes). This residual sink is 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 (IPCC AR5, WGI Chapter 6), although it is acknowledged that some of it may be due to changes in management practice not considered by current models (Erb et al, 2013) and there are uncertainties associated with separating out oceanic fluxes.

***** *The term "land use change" is used by IPCC AR5 WG I (Table 6.1), while for the same estimate the IPCC AR5 WG III uses the term "Forestry and Other Land Uses." Despite the differences between IPCC AR5 and country reporting noted above, the AR5 authors indicate that in both cases the estimate is consistent with the term "LULUCF" as used in GHGIs*.

[65] Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions. All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time (IPCC 2006 Guidelines, vol 4, page 3.6).

3.2. Quantified comparisons between national reporting and independent studies

The Table below compares global estimates of anthropogenic and natural land-related CO_2 fluxes. The Houghton bookkeeping model used in IPCC's AR5 report estimates anthropogenic fluxes based on changes in land use, and some forms of forest management that would occur within a land use category (wood harvest, shifting cultivation, and forest regrowth). As described in the box above, the "residual terrestrial sink" is generally assumed to be a 'natural' response of primary or mature regrowth forests to environmental change (e.g. climate change, fertilizing effects of increased CO_2 and N deposition). By comparison, Grassi et al (2017) estimated the aggregate global anthropogenic fluxes from land use from national reporting, primarily using historical data from INDCs[66] or from other reports submitted to the UNFCCC (GHGI, BURs, NCs), and using FAO datasets (country reporting to FAO-FRA for forest lands and FAOSTAT GHG emissions database for non-forest lands) to gap-fill. An *apparent* significant discrepancy emerges at the global scale from Table 10 between what independent sources (Houghton and Le Quéré et al.) estimate as net "anthropogenic" emissions (around 1.0-1.1 Gt C/y) and what countries report, in aggregate, for LULUCF "managed land" (about 0.2 Gt C/y).

Table 10: Annual global GHG fluxes (Gt C/y) from land: first-order comparison of independent scientific studies versus national reports

Study	Period	Estimate of anthropogenic fluxes	Residual Terrestrial sink
IPCC AR5 (Ciais et al, 2013)	(2000-2009)	1.1 ± 0.8 net land use change (using Houghton bookkeeping model)	-2.6 ± 1.2
Le Quéré et al (2015)	(2000-2009)	1.0 ± 0.5 net land use change	-2.4 ± 0.8
Country reports (INDC, UNFCCC, FAO FRA) from Grassi et al (2017)	(2000-2009)	0.25 ± 0.3 net LULUCF fluxes	Not estimated

To investigate further the apparent discrepancies in Table 10, Table 11 provides estimates of fluxes associated with: (a) Land use change or deforestation (mostly represented by tropical 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 shown in Table 11 in relation to Table 10 suggest a partial reconciliation of the discrepancies between the independent studies and national reports. In particular:

(i) Emissions from deforestation reported by countries (≈0.92 Gt C/yr) reflect reasonably well estimates of land use changes (essentially deforestation) by most independent studies. The differences may be associated with differences between global models vs. country reports in terms of gross vs. net deforestation (although it can be assumed that most country reports focus

[66] Intended Nationally Determined Contributions submitted to the UNFCCC prior to COP21 in Paris.

on gross deforestation, it is not always clear), methods used[67] and pools, gases, and processes included.

(ii) Global models such as Houghton et al (2012a) tend to capture the anthropogenic effects only, by estimating the forest-related emissions based on net forest area change and harvest and essentially assume that, unless harvested, forests remaining forests are carbon neutral. Consequently, a large part[68] 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 reporting. Essentially, the difference lies in the fact that the indirect effects of human activities on managed lands (e.g. climate change induced change in T° and precipitation, human-induced increases in CO_2 and N deposition, etc.) are included in some (especially developed country) GHGIs, but are implicitly categorized as "residual sink" (i.e. "natural") by the IPCC AR5.

The fact that the forest sink estimates (i.e. F→F plus NF→F) reported by countries is much smaller than the residual terrestrial sink estimated by global top down studies can be explained by several factors, including but not limited to: (a) uptake by 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 and therefore not included in national reports. In addition, the residual (terrestrial) sink is calculated as a difference in global budget terms, not a direct estimation of the actual GHG fluxes, and therefore other factors (such as errors and omissions in non-terrestrial flux estimates) may also explain the disparity with national reports.

[67] As explained in the box above, independent studies typically estimate emissions from net land use changes (while countries' reports to UNFCCC typically refers to gross land use changes), and include forest degradation within "land use change" (while countries' reports to UNFCCC include degradation within F→F)

[68] As explained in the box above, *some* of the emissions/removals included by countries in F→F are included in "land use and land cover changes" by global models. However, a comparison of Fig. 11.7 of WGIII of IPCC AR5 (for OECD countries) with Annex I countries' reporting suggests that the *majority* of the sink in F→F in country reporting is not included in the "land use change" estimates reported by IPCC AR5.

Table 11: Comparison of annual GHG fluxes from forest (Gt C/yr)

Study	Coverage	Land use change, or deforestation	F→F	NF→F
Country reports (2000-2010) from Grassi et al. 2017	All countries	≈ 0.92 deforestation (can be assumed mostly gross)	≈ -0.74 F→F	≈-0.29
	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	≈ -0.21 F→F	≈ -0.26
Federici et al. 2015[69] (2000-2010)	Global	1.1 net deforestation**	-0.6 NF→F and F→F (including 0.3 GtC/yr of forest degradation)	
Pan et al. 2011 (2000-2007)	Global	2.8 Tropical gross deforestation	--4.0 NF→F and F→F Excluding unmanaged forests in Canada (118 Mha), Alaska (51 Mha) and West/Central Asia (53 Mha)	
Achard et 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[70] (2000-2005)	Tropics only	0.89 net deforestation** and shifting cultivation (excluding soils)	0.09 net emissions from industrial logging and fuelwood harvest	
Harris et al. 2012a (2000-2005)	Tropics only	0.81 gross deforestation using remote sensing data		
Tyukavina et al. 2015 (2000-2012)	Tropics only	1.02 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.

[69] 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.
[70] Estimate based on Baccini et al (2012); analysis as re-assessed in Harris et al (2012b) and information from IPCC WG3 AR5 Figure 11.8.

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.[71] It is possible that global or pan-tropical aggregates are averaging out actual differences in estimations. The Table below demonstrates such differences at the country level, i.e. comparing one global analyses of deforestation (e.g. Global Forest Watch-Climate[72] which uses Hansen's global analyses of tree cover loss and Baccini's tropical biomass estimates) with country estimates of emissions from deforestation. For country level data, estimates from REDD+ reference level submissions are used for the comparison as they represent the most up-to-date information from countries[73]. At the country level, estimates differ from 5% to over 150%, even though on aggregate the difference is only 7%.

Table 12: Comparison of emissions from deforestation at the country level ($MtCO_2eq$)

Country	FREL	GFW-Climate	% difference
Brazil (2006-2010)	725.3	523	28%
Cambodia (2006-2014)	79.2	55	31%
Colombia (2010-2012)	46.9	22	53%
DRC (2000-2010, 3rd NC)	77.6	198	-155%
Ecuador (2000-2008)	43.4	13	70%
Indonesia (2000-2012)	93.0	215	-131%
Paraguay (2000-2015)	58.8	44	25%
Peru (2010-2014)	53.4	56	-5%
Tanzania (2002-2013)	58.5	26	56%
Uganda (2000-2015)	8.2	10	-22%
TOTAL	**1,224.3**	**1,162**	**7%**

Further exploration beyond emissions from forest loss, highlights how country-level estimates may differ. An analysis[74] of national GHGI reporting from eight countries compared with country level estimates by Houghton and Nassikas (2017)[75] (using the same bookkeeping method as that used for global estimates included in past IPCC Assessment Reports), and other studies is provided below in Table 13.

[71] For example, Arneth et al (2017) argue that while net land emissions is well-constrained, global estimates of gross land use change emissions are underestimated significantly and that the size of the residual sink is similarly underestimated, largely due to the treatment of shifting cultivation and harvested wood products.

[72] County level data may be found at: http://climate.globalforestwatch.org/. Because Hansen data includes temporary losses of tree cover (including trees in non-forest areas), the estimates of deforestation are expected to be higher than country estimates that measure forest (not tree) loss and also should use land use (versus land cover) change, per IPCC Guidelines.

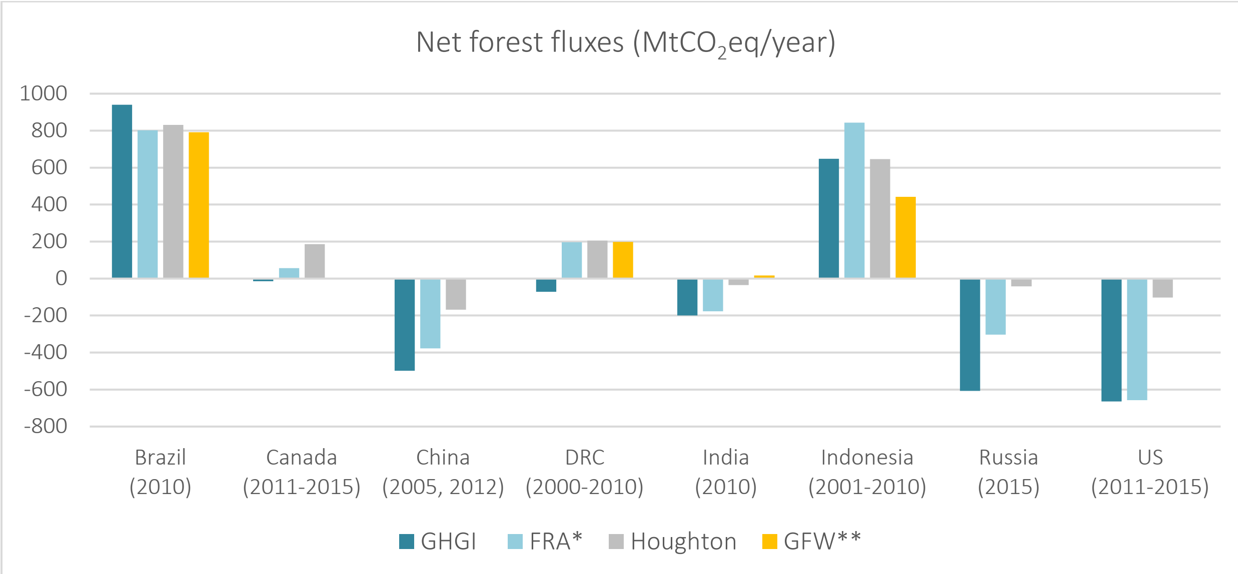
[73] The exception is the DRC, which has not yet submitted a REDD+ reference level, so the most recent GHGI was used (i.e. that found in the DRC's Third National Communication report).

[74] Working paper: *Analyzing national GHG inventories of forest fluxes and independent estimates in the world's top eight forest countries*.

[75] Country data is unpublished; developed for Houghton and Nassikas (2017).

Table: Comparison of country level reporting with independent and other studies

Note: China and Indonesia GHGI figures include some fluxes outside forests (and within peatlands for Indonesia)



Derived from country reports to FAO's Forest Resources Assessment, using the methods in Federici et al (2015)

***Global Forest Watch-Climate only provides GHG forest flux estimates for tropical forest countries*

As suggested in Section 3.1 and 3.2, the "residual sink", not included in some independent estimates, such as Houghton and Nassikas (2017), may be partially or fully accounted in national GHGIs, which estimate all C stock changes (where data is available to the country) on managed land. Other reasons for differences include those discussed in Section 2, such as coverage of activities, pools or gases (e.g. whether non-CO_2 emissions from fire are included) or the use of the managed land proxy. Other methodological differences may also explain why the net emission estimates differ, for example, how fluxes from harvested wood products are estimated, or how an increment factor was chosen or estimated for forests remaining forests. Additional reasons why estimates may differ are included in Section 3. Differences impact both the level and the trend of emissions and removals, and argue for country-level comparisons, particularly if country reporting is the basis for mitigation actions. Studying these differences could also lead to improvements on both sides of the comparison.

3.3. Reasons why independent studies differ from national reporting

In addition to the elements discussed in Section 2 and 3.2, which may apply to independent studies as well as GHGIs (i.e. different views on what is the "anthropogenic sink", different coverage of areas/pools/gases, different methods, etc.), there may be other reasons why there are quantitative differences in estimates. We discuss several of these below.

3.3.1. Forest definition

From a GHGI perspective, the choice of a forest definition will impact the allocation of emissions and removals between forest and non-forest categories, including corresponding transitions. Comprehensive national GHGIs include reporting across all land categories, thus forest definitions should not in principle affect the total estimate of GHG emissions and removals reported by a country. However, if a national GHGI devotes more resources to the forest sector, so that other land uses are not estimated as effectively, then the choice of a forest definitions can affect the quality and inclusion of emission and removal estimates in treed land classified under non-forest land use categories. Comparison of forest-related estimates among independent studies, or between such studies and national inventories, will be more meaningful if the consequences of differences in definition are recognized and taken into account. Differences include:

Parameter values used to define forest: Table 14 shows some parameter values associated with UNFCCC GHGI reporting and the FAO Forest Resource Assessment (FRA) forest definition. Under the UNFCCC, and based on IPCC guidance, countries are expected to choose a value for each parameter and use it consistently over time, and to report on the national forest definition used.

Table 14: Parameters in forest definition of several international conventions

Parameter	UNFCCC	FRA
Minimum area	0.05-1.0 ha	0.5 ha
Minimum height	2-5 m	5 m
Minimum crown cover	10-30%	10%
Minimum time since conversion	Not available	~10 years
Minimum strip width	Not available	20 m
Other parameters covered in definition	Young stands, temporarily unstocked areas	Young stands, temporarily unstocked areas, predominant land use agroforestry

Land use vs. land cover: With a *land cover definition*, land areas estimated to meet the other minimum requirements transfer in or out of forest status according to whether the percentage crown cover definition is satisfied. In the case of a *land use definition* even if tree cover is temporarily removed (i.e. temporarily unstocked) below the minimum percentage requirement (e.g. because of harvest or disturbance), land retains forest status provided regeneration (natural or by replanting) is expected to take place so that all minimum requirements will again be met, perhaps within a specified time period—and so long as a change to another land use has not taken place. Although the IPCC Guidelines call for land use definitions, scientific studies tend to rely on remotely sensed data and use land cover definitions. Countries that use remote sensing data as a basis for estimated activity data (see Section 3.3.2) may be using land cover change, in practice, as an approximation of land use change. A land use definition can be based on remotely sensed data and biophysical properties of the land, for example by determining if a change in tree cover below minimum thresholds is or is not accompanied by observation of substitute land uses like agriculture. Countries may have access to administrative and other national statistical data sources which can be used in making the distinction, provided they are accurate and kept updated. If this is not the case, an additional source of confusion could be introduced, such as when F→NF or NF→F simply result from an administrative reclassification of land rather than a change in its biophysical characteristics.

Exclusion of some types of tree cover: Forest definitions may exclude some types of land with tree cover, e.g. agricultural production systems that include trees or some types of tree plantations (Romjin et al, 2013). For example, while the FAO definition considers rubber plantations as forest, some countries may consider the same area as croplands for the purposes of national GHGI reporting. This may require land use definitions as, for example, some fruit trees can grow more than 5 meters and grow in orchards exceeding minimum crown cover thresholds.

The forest definition chosen determines the boundary of the land that is monitored as forest. Estimation of the effect of forest activities is made more efficient by stratification to differentiate between forest ecosystems and management of disturbance regimes. Comparability between estimates made using the same forest definition does not necessarily require the same stratification scheme, although it is important that estimates are unbiased[76]. This entails use of a valid sampling procedure to estimate the properties of the strata. Examples include use of a higher-quality reference sample to address bias in classification algorithms used with remote sensing, and recognizing that plots gathered for research purposes may not be representative of the strata in which they occur.

Table 15: Forest definitions used in selected studies

Study	Forest definition
Achard at al (2014)	Forests are stratified into 3 classes: i) >70% crown cover, ii) 30% to 70% crown cover, iii) other woody vegetation
Baccini et al (2012)	FAO (by implication)
Federici et al (2015)	FAO
Hansen et al (2013)	Tree cover over 5m height at various crown cover thresholds at the Landsat pixel scale (.09 ha)
Harris et al (2012a)	Forest cover is defined as 25% or greater canopy closure at the Landsat pixel scale (.09 ha) for trees >5 m in height. Includes intact forests, plantations, or forest regrowth. Deforestation is defined as the reduction of canopy cover to below this 25% threshold
Pan et al (2011)	FAO (including temporarily unstocked areas and plantations)
Saatchi et al (2011)	>10% tree cover as defined by the MODIS vegetation continuous field product
Tyukavina et al (2015)	Any vegetation taller than 5m with canopy cover ⩾25% (both natural forests and plantations)

3.3.2. Activity data

Activity data, according to the IPCC Guidelines, are defined as data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time. In the case of land-use changes, these data are normally provided in terms of area (e.g. hectares of land in a particular year that changed from forest to non-forest). In the case of forest remaining forest, activity data are provided in

[76] Technically this means that they are made using unbiased estimators, or statistical procedures that do not carry the expectation of bias

terms of area and also other variables related to emissions (e.g. harvest volumes or amount of biomass burned in a fire event). Tradeoffs in the spatial resolution, frequency, and costs of data used to generate information about forests mean that there are limits on the detail and frequency at which countries can identify forest losses and gains. Remote sensing observations from optical satellites, often integrated with NFIs, lie at the heart of current forest monitoring for forest area change.

Forest definition (Section 3.3.1) and the differentiation between managed and unmanaged land (Section 2.2.1) are two factors that can substantially influence differences in reported activity data. Below are additional reasons why activity data may differ even when the same areal extent is being monitored.

Spatial Resolution: Spatial resolution is important in cases where remote sensing data forms the main input for estimating forest area and area change. Landsat (30 m resolution, or ~0.09 ha pixel area at the equator) is most widely used because of its free availability and long historical archive. Other spatial resolution may be used from RapidEye (1-5 m resolution, or 0.0001 to 0.0025 ha pixel area; may be of use in detecting degradation) to MODIS (250 to 500m resolution, or 6.25 to 25 ha pixel area; high temporal resolution and useful spectral indices for detecting change; also freely available). In spite of higher resolution of raw data, resampling to lower resolutions and the use of larger minimum mapping units is common—either to increase data processing efficiency or to comply with national definitional thresholds. For countries where land use is fragmented, studies using different spatial scales may result in significant difference in GHG estimates. For example, where small plots of croplands intermix with similar sized forests and villages, a larger pixel size or minimum mapping unit may not detect clearing of small forest patches or tree planting that would be detected by a smaller pixel size, resulting in different estimates of forest fluxes.

Remote sensing analysis approach used: To analyze forest change, two different approaches are used: the more traditional approach of mapping land classes and changes at sequential time points vs. a more recent "follow the pixel" approach (e.g. used by Hansen et al, 2013 and more recently at MapBiomas[77]). The choice may significantly impact quantified results. There are trade-offs, however, in each approach—the former allows quantification of transition in multiple land use and land cover types, while the latter is currently limited (particularly for global analyses) to transitions from forest to non-forest[78], but allows for the use of all available data and, therefore, a more complete time series analysis. Visual interpretation of remote sensing products (e.g. using tools such as Collect Earth) may be used to derive activity data and to obtain reference data that can be used with mapped data to produce unbiased estimators that result in increased accuracy and lower costs. However, it may require significant human resources to interpret multiple points which may also vary, particularly for larger territories.

Temporal resolution: Reliable estimates of carbon dynamics require detailed observations of land cover change on an annual basis; missing a single year of observations can lead to substantial errors, especially in ecosystems with rapid forest regrowth. Although UNFCCC reporting is based on a one-year timeframe (for Annex 1 countries), estimation of annual activity data is likely to be reported on the basis of *average* rates of land-use conversion, as determined by measurements made at longer intervals (e.g. 5-10 year periods). Although using longer time intervals is common practice, technically, remote sensing approaches to monitor forest area change can be made annually and even sub-annually (e.g., Brazil's PRODES monitoring system, Hansen annual forest loss, GLAD weekly forest change alerts). Moscarro et al

[77] https://storage.googleapis.com/mapbiomas/Metodologia_Mapbiomas_23Nov2015.pdf
[78] A single tree cover gain estimate is provided for the period 2000 to 2012

(2015) conclude that higher temporal resolution remote sensing products improve carbon dynamics estimates and can capture inter-annual variability in forest dynamics.

Sampling vs. wall-to-wall coverage: Statistically sound sample based estimates (e.g. from NFIs) are well understood and the estimators used, if properly implemented, are unbiased. Remote sensing estimates, even if wall-to-wall, may have bias entering through the classification algorithms (e.g. Heinz et al, 2015). For this reason, it will often be most efficient in terms of resources for countries to use unbiased estimators which combine remote sensing and sample reference data[79]. This approach can help explain apparent differences between global mapping (usually wall-to-wall) and national estimates (usually sample-based), e.g. where certain types of tree cover are not included in national forest definitions.

Table 16: Approaches to estimating activity area in selected independent studies.

Study	Area estimation
Achard at al (2014)	Sampling 4000 10x10 km sites based on interpretation of Landsat pixels
Baccini et al (2012)	Taken from FAO FRA 2010
Federici et al (2015)	FAO FRA 2015 subcategorized by primary forest, other naturally regenerated forest, and planted forest
Hansen et al (2013)	Landsat data
Harris et al (2012a)	MODIS data calibrated with Landsat data (i.e., Hansen product prior to wall-to-wall Landsat)
Pan et al (2011)	Various: national forest inventory data, FAO data and remote sensing
Saatchi et al (2011)	MODIS
Tyukavina et al (2015)	Sample-based approach using a stratified random sample, with strata derived from the wall-to-wall forest cover loss map of Hansen et al. (2013) to separate the gross loss of forest biomass into losses from natural forests and losses from managed forests including plantations, agroforestry systems and subsistence agriculture.

Activity Data for Forests Remaining Forests

In the case of forests remaining forests, where countries apply the gain-loss method of the IPCC Guidelines, activity data other than area may be relevant such as biomass losses from wood harvest, fuelwood collection and natural disturbance (subtracted from biomass gains from forest growth). Estimates for biomass losses used in national GHGIs for the category of forests remaining forests rely primarily on information collected by national forest departments on extracted wood volumes (although official logging statistics are likely to exclude informal or illegal harvests, which may be significant and should be included in national GHGIs). Biomass loss from fuelwood collection, particularly for countries where these losses can be substantial, sometimes relies on FAOSTAT data (as communicated by countries or gap-filled by FAO), which does not include illegal harvest. In the case of monitoring natural disturbances, some developed countries use carbon budget models to simulate ecosystem response to natural disturbance. Such models are a well-established approach to estimating carbon fluxes at regional to national scales. For example, Canada's National Forest Carbon Monitoring Accounting and Reporting System (NFCMARS) uses the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). Individual U.S. agencies monitor disturbances such as fire, hurricanes, insect damage and drought, but these data are not used explicitly in the U.S. forest inventory (the U.S. GHGI uses the stock-difference method).

[79] This issue was discussed in the context of global mapping at the 2015 GFOI-GOFC GOLD expert workshop on Using Global Datasets for National REDD+ Measuring and Monitoring, see http://www.gfoi.org/rd/fourth-rd-expert-workshop/

3.3.3. Emission factors

Emission factors (EFs) quantify GHG emissions or removals (or C stock change) per unit activity per year. Usually, in the case of forestry and other land use, activity is measured by area, so EFs are expressed per unit area. Examples of EF include carbon densities, in each pool, before and after a transition from forest to another land use (in which case the difference is multiplied by the area transferred per year and divided by the number of years the pool needs to achieve the new C equilibrium stock), or they may be a change in carbon density over time, which is multiplied by an area of forest in which the change is taking place. EFs corresponding to transitions between forest strata may be used to estimate emissions and removals associated with degradation. EFs are also used to quantify non-CO_2 GHG emissions, e.g. from fire. In integrated, IPCC Tier 3 models EFs can be thought of more generally as model parameters—e.g. rates of transfer between pools—that are not a function of the activity data used to drive the model.

When establishing comparability between scientific studies or with inventory data, issues relevant to emission factors include:

Coverage: National inventories may measure EFs for some pools and use default values for others. The pool for which EFs are most often measured directly is above ground-biomass and frequently below-ground biomass is added using root-to-shoot ratios. EF for drained organic soils are important for some ecosystems, and for peat fires. Independent scientific studies may not be comparable to GHGIs if they do not have the same pool coverage (see Section 2.2.2 on completeness of reporting).

Values: Langer et al (2014) have compared IPCC default AGB values for use in forest land conversion with those from the Saatchi and Baccini datasets, and found on average that the latter are lower by 35% and 24% respectively. The difference falls to 13% and 1% respectively for intact forest landscapes, leading to a conclusion that the IPCC defaults seem to refer mainly to intact forest landscapes.

The Table below compares carbon densities corresponding to total biomass of independent studies and country-specific values.

Table 17: Average forest carbon density estimates (tC/ha) in above- and below-ground tree biomass for top ten tropical countries with highest emissions from deforestation

Country	Saatchi et al (2011)*	FAO FRA (2015)	Baccini et al (2015)	Country FREL (where available)
Brazil	123 (110 – 136)	119	124 148 (Amazon)	152 (30-263) for Amazon) 52 – 103 (Cerrado)
Indonesia	158 (143-172)	162	149	60-142** (EFs specific to forest type)
Colombia	141 (127-155)	151	132 156 (Amazon)	154 (Amazon biome)
Bolivia	94 (82-106)	78	104	
Madagascar	78 (71-84)	130	137	
DRC***	134 (120-144)	127	138	179 (dense forest class) 108.5 (secondary forest)
Peru	160 (145-174)	114	154	11-140 (EFs specific to forest type)

Mexico	52 (43-61)	63	75	19-42 (EFs specific to forest type) 4-6 (EFs other woody vegetation)
Malaysia	180 (164-196)	120	146	
Paraguay	27 (19-35)	No data reported	49	28-66 (EFs specific to forest type)

***** Numbers in parentheses for Saatchi et al indicate uncertainty bounds
** Aboveground biomass only
*** Information from reference level submitted to the FCFP Carbon Fund

Time dimension: IPCC EFs are based on historical data and this is often the case for country-specific emission factors, e.g. where these are established on the basis of historical surveys or statistically representative research plots. However, the real underlying relationship between area and emissions that is represented by an emission factor may be changing over time rather than static. When repeated surveys are used, such as periodic national forest inventories, any gradual change in EFs e.g. due carbon fertilization, N deposition or temperature and rainfall trends will be taken into account. For this reason, EFs based on historical data may need to be updated periodically to continue to represent conditions on managed land, and to represent the impact of new management practices, e.g. standing forest biomass is often used to estimate deforestation emissions. This parameter is updated every time a NFI is carried out, i.e. the EF for deforestation will vary with time. Country reporting to the FAO FRA suggests that many countries do not change their biomass estimates (i.e. C stock per forest strata) between assessments and, therefore, it may be assumed that changes in emissions and removals are mostly reflective of activity data changes (e.g. conversions to and from forest).

If EFs (e.g. rate of tree growth) are measured annually there may be considerable variation due to year-on-year variation of environmental conditions (as opposed to long term trends discussed in the paragraph above). In this case, measurements should be continued for a sufficient period to remove the inter-annual fluctuations. In the case of HWP estimates, there may be a significant difference in emissions and removals according to whether the wood in HWP is assumed to be emitted instantaneously at the point of harvest, or whether the dynamics of product decay is considered explicitly.

Stratification: Factors affecting the amount of GHG emissions/removals include climate, soil, vegetation, management practices (including those leading to forest degradation or restoration), so that the land needs to be stratified accordingly. Stratification increases sampling efficiency. EFs calculated for different levels of stratification allow estimation of equivalent GHG balances at the highest (least detailed) level of stratification.

Measurement of EFs: Where EFs are measured they should correspond to the activity data strata or drivers that they refer to. The sampling to achieve this should follow an accepted statistical scheme and an explanation should be provided as to why the results are expected to be free of bias. Expected uncertainty should also be quantified; IPCC Guidelines suggest using an uncertainty range corresponding to the 95% confidence interval.

Methods: EFs can be calculated as C stock changes or as GHG fluxes. C stocks are derived through inferences/models based on conversion and/or expansion factors and/or allometric equations from measurements (diameter, height, soil samples, DOM samples, above and below ground turnover, tree models). Consequently, the model applied to ground measurements for calculating C stocks may be a source of differences among EFs, although such source varies significantly among developing and developed countries (Chave et al, 2005; Holdaway et al, 2014), and among tropical and boreal forests.

Table 18: Pool coverage and methods to calculate EFs in various independent studies

Study	Pool coverage	EF method of calculation
Achard at al (2014)	AGB expanded to total biomass	Drawn from merging of FAO ecosystem map, IPCC default data and Baccini and Saatchi maps
Avitabile et al (2016)	AGB	Fusion of Baccini and Saatchi maps using reference data points for bias correction
Baccini et al (2012)	AGB	LiDAR calibrated with field data and upscaled using MODIS
Federici et al (2015)	AGB expanded to total biomass	FAO FRA 2015 data
Harris et al (2012a)	AGB expanded to total biomass	Saatchi biomass map
Pan et al (2011)	Total biomass, deadwood, soils	Various: NFI data, national models, expansion factors, ecosystem and bookkeeping models
Saatchi et al (2011)	AGB expanded to total biomass	Lidar calibrated with field data and upscaled using MODIS and radar data
Tyukavina et al (2015)	AGB expanded to total biomass	65m GLAS biomass data per stratum

3.3.4. Uncertainties

In order to make meaningful assessments of the differences among estimates of GHG fluxes, it is necessary to know the precision of each estimate. Two estimates may be different but not contradictory if they fall within each other's uncertainty bounds.

Independent studies employ diverse approaches for uncertainty analysis, while the IPCC Guidelines give national reports a common framework. However, some national reports (and independent studies) can be incomplete in their estimation of uncertainties. Most independent studies and national GHGIs (particularly of developed countries) apply simulation and error propagation techniques, and quantify random errors. Statistically valid sample reference data should provide estimates that, consistent with the IPCC's definition of good practice, *neither over- nor under-estimate* (the true value) *so far as can be judged*. Considerable progress has been made in defining methods to achieve this, using reference data alone, or reference data and remote sensing data in combination[80].

Most developed countries, such as the United States and Canada, provide a high level of detail on a systematic approach to assess uncertainties in estimation. Brazil and Indonesia have undertaken initial steps towards building an approach for uncertainty analysis of their national GHG inventories. However, most developing countries' national reports have high potential to improve uncertainty analysis in GHG estimation. Many do not report at all on uncertainties.

At a global level, independent studies have uncertainties around 20%-30% for GHG emissions of F→NF (Table 19). At the level of individual countries, especially developing countries, uncertainties are expected to be higher. The Table below provides several examples of reported uncertainty estimates.

[80] The GFOI Methods and Guidance Document provides such guidance: http://www.gfoi.org/methods-guidance/

Table 19: Uncertainties in selected independent scientific studies and national GHGI reports*

Study/Report	Reported uncertainty		
	Forest conversion (area data)	GHG from F→NF	GHG from F→F
Achard et al 2014	+/-4-10% + bias 11.2% (95%)	+/- 30% (95%)	
Pan et al 2011		+/-16% (95%)	+/-21% (95%)
Hansen et al 2013	+/- 2% (95%)**		
USA NIR 2017		FL→Cropland: +/-76% (95%) FL→Grassland: +/-87% (95%) FL→Settlements: +/-43% (95%)	+/-37% (95%)
Canada NIR 2017	+/-30% (95%)	+/-34% for CO_2 (95%) +/-27% for CH_4 (95%) +/-14% for N_2O (95%)	-34% +6% for CO2 (95%) -30% +119% for CH_4 (95%) -30% +129% for N_2O (95%)
Brazil 3rd NC (2016)	Only aggregate uncertainties reported (i.e. for all GHG, forest category uncertainties not reported)		
Indonesia 1st BUR (2015)	Only aggregate uncertainties reported (i.e. for all GHG, forest category uncertainties not reported)		
DRC 3rd NC (2015)	No uncertainty analysis undertaken		

*Either reported as such or implied by reported uncertainties; "(XX%)" stands for "around the mean with XX% confidence"
** Refers to error for values provided at the global level; uncertainties at the country level would be higher.

4. Conclusions and Recommendations

The Global Stocktake will require recognizing the differences between independent estimates of forest-related fluxes and national GHG reports, if it is to assess the current “gap” between existing pledges and the net emissions reduction require to achieve the Paris Agreement’s long term mitigation goals. Therefore, without moving towards reconciling the differences highlighted in this report and in similar studies (e.g. Grassi et al, 2017)—or at least understanding the reasons for these differences—progress toward the "well below 2°C" target will be difficult to assess. This will require an effort in gaining mutual understanding and cooperation between the scientific community and the developers of national GHG inventories.

Key conclusions from this assessment:

Independent research and national reporting of GHG forest fluxes have different objectives. Independent research has a different role than national reports and often starts with a different objective, for example, to publish new results often using new and improved methods and technology. In contrast, national reporting aims for regularly collected data and methodological consistency over time. In addition, national reports must follow internationally agreed methods (developed by the IPCC) and often use as a basis national data and definitions (i.e. those used to inform management and policy decisions).

Even when both are based on reliable data, results from independent research and national reports may vary. This can be due to differences in scope (i.e. included processes and activities, land categories and conversions, C pools and gases), temporal window analyzed, and also in datasets used. The use of different methodologies can also lead to different quantified results, for example, the estimation methods used, how legacy emissions are included, how harvested wood products are treated, or whether and how natural disturbances are included. These differences also exist among independent research (and therefore such studies themselves may be difficult to compare). By contrast, comparisons between national reports are facilitated to a degree by the use of common methodologies and common reporting format tables.

The most significant reason independent studies and national reports are not easily comparable is likely due to differing treatment of, or the ability to capture, anthropogenic removals. There are varying approaches to distinguishing anthropogenic effects (direct or indirect) from natural effects on emissions and removals. The scientific studies supporting the IPCC AR5, for example, separate the estimation of direct-human induced effects (e.g., land use change, harvest) from the residual sink (due to both natural and indirect human-induced effects—such as CO_2 and N fertilization and change in temperature and length of growing season). By contrast, most national reports estimate together both direct and indirect human-induced effects (often because of the difficulty of separating them) on what each country defines as “managed land”, and ignore GHG fluxes on unmanaged lands.

Another important reason for differences is the inability (largely by developing countries) to fully capture all forest-related removals. This may be due to incomplete estimation of processes, C pools, or other data and capacity gaps. In the case of national reports for Annex I countries the international review process has been instrumental and has enabled the continuous improvement (and subsequent recalculation of time series) of GHG estimates. GHGIs in developing countries—likely due to the fact that such reports have not benefited so far from a periodic review process—are often incomplete and transparency in how estimates were derived needs to be improved.

Reproducing estimates from research studies or national reports is often difficult due to a lack of information. Independent studies, and some national reports, are not clear or sufficiently detailed on what underlying data sources or methods, assumptions, or model inputs, were used to estimate forest fluxes. Reconciling differences among results will not be possible unless such information, as well as robust calculations of uncertainties, are provided in both independent research and national reports. Furthermore, understanding the differences would be facilitated by the disaggregation of GHG estimates, that allow for relevant comparisons.

Global comparisons will be useful for the global stocktake, but country comparisons are equally critical since country reporting is the basis for mitigation actions by countries. They are also the fundamental basis for bottom up estimations (including those included in IPCC AR reports) and will be used to track progress in the implementation of NDCs. Therefore, understanding differences between forest flux estimates not only needs to occur at a global scale, but also at national scale. Comparative analyses, review and discussions of GHG estimates at the national scale not only increase the credibility of estimates, but also can help to build the capacity of the institutions developing the systems and methods used to produce national reports.

Several recommendations on how to improve the understanding of the role of forests in the global carbon budget include:

Future IPCC reports should seek to transparently describe and discuss differences between independent studies and national GHG estimates. In particular, the IPCC should seek both achieving greater consistency (or at least greater transparency) between definitions and methods used across Assessment Reports' Working Groups[81] and Special Reports when estimating forest-related GHG fluxes, and providing clarification of differences with country reports such as those highlighted in this report.

To understand why estimates may differ, each source of information should provide transparent documentation on how estimates were derived. Such documentation is a requirement for national reports, although in practice national reports do not always provide detailed information on data and methods. The review and assessment processes under the UNFCCC, however, promotes continuous improvement over time, identifying areas for improvement and greater transparency from countries. Papers published in scientific journals are typically linked to a particular research question or agenda and are, in almost all cases, peer reviewed. However, unlike national GHG reports, independent studies have no requirement to be consistent in estimating fluxes over time, or to use consistent data and methodologies—resulting in estimates that are not necessarily comparable among them and with national GHG reports.

Improving the capacity of developing countries to estimate and submit more complete GHGIs should be a priority. There is considerable scope for improving national estimates of forest-related GHG fluxes, particularly in developing countries and particularly to estimate fluxes from forest degradation, forest regrowth and reforestation. Beyond a need for better data sources, there is ample scope for improving technical skills of GHG inventory teams and the institutional arrangements around GHG inventory compilation. Increasing the use of the 2003 Good Practice Guidance and/or 2006 Guidelines will improve

[81] In particular, Working Group I (scientific basis) and Working Group III (mitigation).

the transparency and comparability of national forest flux estimates and assist the analyses for the global stocktake. While technical (and financial) assistance should be provided where needed to increase capacity, developing countries must also prioritize and institutionalize this capacity domestically.

Increasing awareness in the scientific community of the information contained in national GHGIs can enhance the policy relevance of independent research. An effort should be made to increase the knowledge, beyond national GHGI compilers, of IPCC methods and data used in GHGIs, and to better communicate the needs of the GHG inventory community. Independent studies could seek greater comparability with the methodological guidance provided by the IPCC Task Force on GHG Inventories, including, to the extent possible, on the level of disaggregation in terms of categories and sub-categories, C pools, managed vs. unmanaged land and direct vs. indirect effects. Independent studies may also focus on currently under-served regions (e.g. dry forests in Africa), or areas where uncertainty levels of national GHG estimates are high (e.g. forests remaining forests or land converted to forests in developing countries), and results could also contribute to the IPCC Emissions Factor Database. The scientific community could also help to distinguish and clearly document those fluxes that are outside of the GHGI framework (e.g. from unmanaged forest) but are nonetheless of substantial importance for global monitoring purposes in the context of the Paris Agreement.

Efforts to reconcile independent and national GHG forest flux estimates and explain the sources of significant differences should be encouraged. For example, where there are independent estimates consistent with IPCC GHG inventory methods, countries may use them for verification of their GHG estimates. This should be encouraged by the inventory review and assessment process, as it would help to increase the overall confidence of national estimates. Countries lacking in data may consider using results from literature (e.g. emission factors), for example, to be able to include the full range of carbon pools. Countries that have significant areas of unmanaged land should be encouraged, where possible, to estimate and report information on emissions and removals on these lands even though they are not included in national GHGIs. Independent studies (e.g. on emissions from permafrost thaw, etc.) or data (on the extent of, e.g. wildfires or pest outbreaks) may help in doing so.

Implementing these recommendations can help in ensuring that reporting on mitigation in the forest sector will be credible in the context of the global stocktake. This is a pre-requisite to allowing the full mitigation potential of forests—critical for reaching carbon balance by the second half of the century—to be achieved.

Annex I: Glossary and Acronyms

Aboveground biomass	AGB	All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.
Activity data	AD	Data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time.
Annex I	AI	Parties listed in Annex I to the Convention include the industrialized countries that were members of the Organization for Economic Cooperation and Development (OECD) in 1992, plus countries with economies in transition, including the Russia Federation, the Baltic States, and several Central and Eastern European States.
Assessment Report	AR	Published materials by the IPCC composed of the full scientific and technical assessment of climate change, generally in three volumes, one for each of the Working Groups of the IPCC, together with their Summaries for Policymakers, plus a Synthesis Report.
Black carbon	BC	The most strongly light-absorbing component of particulate matter composed of pure carbon, formed by the incomplete combustion of fossil fuels, biofuels, and biomass. It is emitted in both anthropogenic and naturally occurring soot.
Belowground biomass	BGB	All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Biennial Report	BR	Submissions by developed countries that outline their progress in achieving emission reductions and the provision of financial, technology and capacity-building support to developing countries.
Biennial Update Report	BUR	Submissions of developing countries to the UNFCCC that provide an update of the information provided in National Communications, in particularly on national GHGIs, mitigation actions, constraints and gaps and support needed and received.
Carbon	C	A chemical element common to all known forms of life.
Carbon dioxide	CO_2	The most relevant GHG related to forests.
CO_2 equivalent	CO_2e	A quantity used to describe the global warming potential of a given mixture of GHGs that would be equivalent to CO_2 emissions over a specified timescale (e.g. 100 years).
Conference of the Parties	COP	The supreme body of the UNFCCC. It currently meets once a year to review the Convention's progress.
Dead organic matter	DOM	Litter and woody debris; in GHGIs, DOM refers to the combination of DW and L.
Democratic Republic of Congo	DRC	A country in the Congo Basin with the 6th largest forest area in the world.
Dead wood	DW	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.
Emission factor	EF	A coefficient that quantifies the emissions or removals of a gas per unit activity. EFs are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.
Forest	F	Forests are not defined for reporting under the Convention. The *IPCC Guidelines* encourage countries to use detailed ecosystem classifications in the calculations and in reporting broad specified categories to ensure consistency and comparability of national data across countries.

Food and Agriculture Organization	FAO	An intergovernmental organization that includes among its goals to "make agriculture, forestry and fisheries more productive and sustainable".
Flux		In this paper, fluxes refer to all GHG emissions and removals from land, which includes (direct and indirect) anthropogenic and natural impacts.
Forest Resources Assessment	FRA	A report of the FAO every five years that provides a global assessment of forests. Countries submit country-specific information that is used, along with additional remote sensing information, to inform the FRA.
Forest reference emission level	FREL	A national forest reference emission level and/or forest reference level or, as an interim measure, subnational FRELs, is one of the elements to be developed by developing countries Parties implementing REDD+ activities. FRELs are expressed in tons of CO2 equivalent per year for a reference period against which the emissions and removals from a results period are compared. Thus, reference levels serve as benchmarks for assessing each country's performance in implementing REDD+ activities. Reference levels need to maintain consistency with the country's GHGI estimates.
Good Practice Guidance	GPG	In 2003, the IPCC developed Good Practice Guidance for Land Use, Land-use Change and Forestry
Greenhouse gas	GHG	The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
Greenhouse gas inventory	GHGI	A report that covers emissions and removals of GHGs; submissions of GHGIs to the UNFCCC follow IPCC Guidelines for National GHG Inventories (www.ipcc.ch).
Hectare	Ha	A metric unit of area.
Harvested wood product	HWP	All wood material (including bark) that leaves harvest sites (slash and other material left at harvest is regarded as DOM). The IPCC provides guidelines for estimating the time carbon is held in HWPs, depending on the product and its uses.
International consultation and analysis	ICA	A form of review under the UNFCCC intergovernmental process that applies to developing countries and, in particular, to submitted BURs.
Intergovernmental Panel on Climate Change	IPCC	Established in 1988 by the World Meteorological Organization and the UN Environment Programme, the IPCC surveys world-wide scientific and technical literature and publishes assessment reports that are widely recognized as the most credible existing sources of information on climate change. The IPCC also works on methodologies and responds to specific requests from the Convention's subsidiary bodies. The IPCC is independent of the Convention.
Kyoto Protocol	KP	An international agreement linked to the UNFCCC, which commits its Parties by setting internationally binding emission reduction targets.
Litter	L	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil.
Land use, land-use change and forestry	LULUCF	A greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities. The 2006 IPCC Guidelines refers to AFOLU (Agriculture, Forests and Other Land Use) which is subdivided into two sectors including agriculture and land use (LULUCF). In this report, we refer to LULUCF as simply "land use". This paper is focused primarily on forest-related sources and sinks, a further subset of the land use sector.
Measurable, reportable and verifiable	MRV	A process/concept that potentially supports greater transparency in the climate change regime.

Nitrogen	N	A chemical element and one of the primary nutrients critical to the survival of all living organisms.
National Communication	NC	A document submitted in accordance with the Convention (and the Kyoto Protocol) by which a Party informs other Parties of activities undertaken to address climate change. Annex I Parties provide information on GHG emissions and removals, national circumstances, policies and measures, vulnerability assessment, financial resources and transfer of technology, education, training, and public awareness; and any other details of the activities a Party has undertaken to implement the Convention. Non-Annex I countries provide information on GHG inventories, measures to mitigate and to facilitate adequate adaptation to climate change, and any other information that the Party considers relevant to the achievement of the objective of the Convention.
Nationally determined contribution	NDC	According to Article 4 paragraph 2 of the Paris Agreement, each Party shall prepare, communicate and maintain NDCs that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.
Non-forest	NF	See forest.
National forest inventory	NFI	The systematic collection of data and forest information for assessment or analysis.
Non-Annex I	NAI	Countries that have ratified or acceded to the UNFCCC that are not included in Annex I of the Convention, i.e. developing countries.
	REDD+	Reducing emissions from deforestation, reducing emissions from forest degradation, conservation of forest carbon stocks, sustainable management of forests, and the enhancement of forest carbon stocks; a concept developed under the UNFCCC that involves “policy approaches and positive incentives” including results-based finance.
Soil organic matter	SOM	Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.
United Nations Framework Convention on Climate Change	UNFCCC	The UNFCCC is a “Rio Convention”, one of three adopted at the “Rio Earth Summit” in 1992. Preventing “dangerous” human interference with the climate system is the ultimate aim of the UNFCCC.

Annex II: References

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