CASE STUDIES

Analyzing national GHG inventories of forest fluxes and independent estimates in the world's top eight forest countries

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Contents

Introduction and objectives

The report ***GHG fluxes from forests: An assessment of national GHG estimates and independent research in the context of the Paris Agreement*** seeks to clarify what is (and is not) included, generally, in national greenhouse gas inventory (GHGI) reports. It explains issues such as the IPCC's approach to separate anthropogenic from non-anthropogenic fluxes (i.e. the "managed land proxy"), as well as identify capacity gaps related to land use sector reporting. It includes a comparison of the global aggregate of forest-related GHG fluxes contained in national GHGI reporting with independent (mostly global) studies. This companion document is an attempt to scale down the analysis to the national level, focusing on eight countries that together account for 62.3% of global forest area.

Forest area of the eight case studies considered in this report

	Brazil	Canada	China	DRC	India	Indonesia	Russia	US	TOTAL
Forest area* (million ha)	493.5	347.1	208.3	152.6	70.7	91.0	814.9	310.1	**2,488.2**
As % of global forest area*	12.3%	8.7%	5.2%	3.8%	1.8%	2.3%	20.4%	7.8%	**62.3%**

**FAO FRA 2015 data used*

Each case study includes:

1) "What's in and what's out" of national reporting of GHG fluxes.

The analysis is based on GHGIs submitted to the UNFCCC through National Communications, Biennial (Update) Reports and National Inventory Reports. It clarifies what forest fluxes countries have included in their national GHGI, as well as what significant fluxes may not be reported—either because they are not required (per IPCC guidance) or are not included because the GHGI is incomplete.

2) Comparison of national GHG estimates of forest fluxes with independent studies.

For each country, a comparison was made with a range of other estimates of forest fluxes. All case studies include data from Houghton and Nassikas (2017)[1], which uses the same (bookkeeping) methodology that underlies global assessments by Working Group 1 in IPCC Assessment Reports to date. In most cases a comparison was made with alternative country statistics or reporting, such as country reports to FAO's Forest Resource Assessment (FRA). Other comparisons may also be included where relevant independent estimates were available[2]. Where possible, an effort was made to explain (or propose a hypothesis) why estimates may have differed.

3) Summary of forests in Nationally Determined Contributions.

Finally, a brief summary is provided for each country on how they included forests in their NDC and any implications from the analysis.

[1] Country level forest flux estimates were calculated for Houghton, R.A. and A.A. Nassikas (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Global Biogeochemical Cycles,* 31:456-472, doi:10.1002/2016GB005546. Hereafter referred to as "Houghton" data.

[2] For example, data from Global Forest Watch, which combines forest cover change data from the University of Maryland (Hansen's dataset) with forest biomass from WHRC/Baccini et al, 2015.

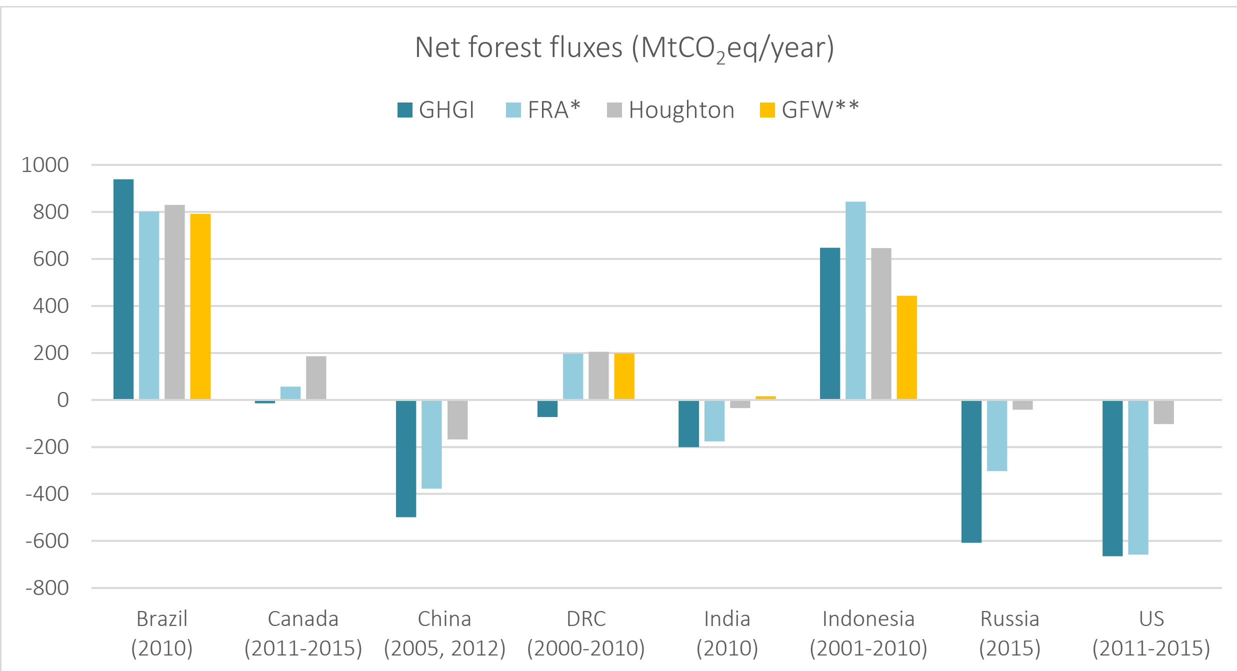
Lessons learned from the case studies

A number of lessons were learned from analyzing forest fluxes found within national GHGIs (of the world's eight top forest countries) and comparing them with other (including independent) estimates. Such insights may be useful for independent researchers developing estimates of GHG fluxes from forests, countries preparing GHGIs, as well as for the Global Stocktake (or facilitative dialogue in 2018) under the UNFCCC. These lessons are summarized below.

There are *apparent* discrepancies between countries' official data and independent estimates of forest-related GHG fluxes—but these do not mean either estimate is incorrect or inaccurate. The table below provides a compilation of estimates of net forest fluxes from national GHGIs compared with estimates derived from country reporting to FAO's Forest Resources Assessment (FRA)[3], Houghton and (for tropical forest countries only) Global Forest Watch[4]. At the level of individual countries, it may seem—at first glance—that there are significant discrepancies between estimates contained in GHGI reports and other sources. The comparison between net forest fluxes in GHGIs and Houghton, for example, across the eight countries alone, amounts to over 2 $GtCO_2eq$, and are not always of the same sign.

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 combines data from University of Maryland (Hansen) with the biomass map from WHRC/Baccini*

[3] Federici (2017), unpublished. Country forest fluxes derived using FRA data and methods developed for Federici, S. et al (2015). New estimates of CO2 forest emissions and removals: 1990-2015, Forest Ecology and Management 352, pg 89-98.
[4] Global Forest Watch-Climate (climate.globalforestwatch.org) provides estimates of emissions from gross deforestation by combining data from Hansen et al (2015) and Baccini et al (2012).

The data seems to support preliminarily, in line with the main report, the hypothesis that different concepts of "what is anthropogenic" have large implications for GHG forest flux estimates. National GHGIs are meant to only estimate anthropogenic emissions and removals by excluding all GHG fluxes from areas that countries designate as "unmanaged" (i.e. the approach known as the "managed land proxy"). For Russia, Brazil and Canada, the difference in forest area considered varies by 33%-52% (see Table below). On the other hand, once lands are considered managed, GHGIs measure *all* carbon stock changes (e.g. including growth from CO_2 and N fertilization) on such lands, which may explain some of the discrepancy between the sinks in official data from, e.g. Canada, Russia and the United States, compared to Houghton's lower calculations of net removals (which estimate only *direct* human-induced effects).

Managed and unmanaged forest area in eight case studies

Note: Some developing countries use the 1996 IPCC Guidelines (which does not include the managed land proxy), or the GHGI does not indicate a separation of managed vs. unmanaged (implying that all land is considered managed); primary forest area (figures based on country reporting to FAO FRA 2015) may be seen as one proxy for "unmanaged" forest area.

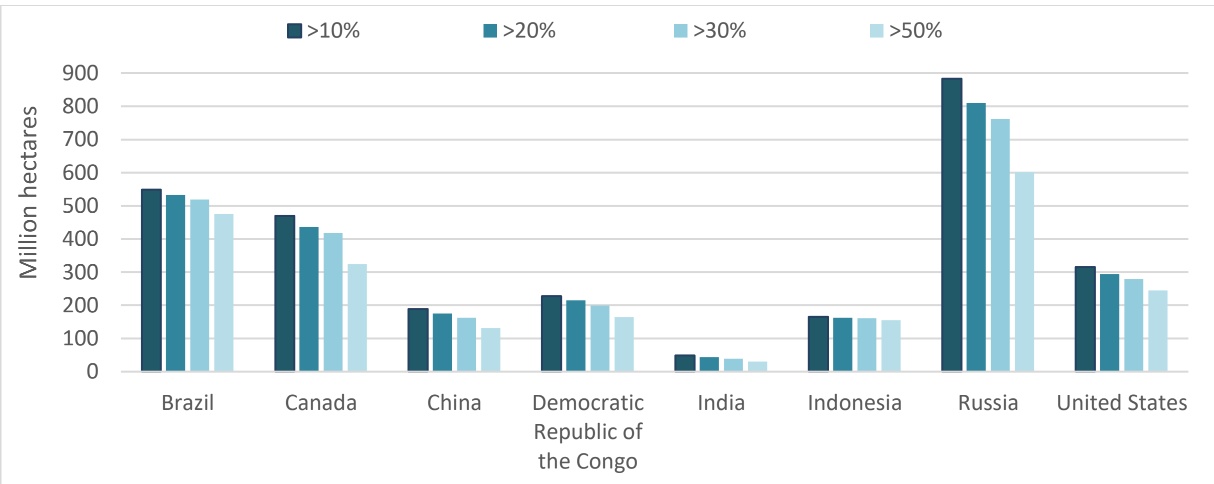
Country	Total forest area as reported in GHGI (M ha)	Forest area considered managed (M ha)	% Unmanaged	% of forest area identified as primary forest*
Russia (CRF, 2017)	897	685	24%	33%
Brazil (3rd NC, 2016)	494	235	52%	41%
Canada (NIR, 2017)	347	226	35%	59%
United States (CRF, 2016)	304	294	3%	24%
China (BUR, 2016)	208	208	0%	6%
DRC (3rd NC, 2015)	150	150	0%	67%
Indonesia (BUR, 2016)	128	128	0%	51%
India (BUR, 2015)	70	70	0%	22%

Estimates are sometimes not comparable, simply because they measure different things. The way in which data is aggregated or disaggregated can obfuscate a comparison. For example, GHGIs represent land-related emissions and removals by land-use transitions (forests to non-forest, non-forest to forest, forests remaining forests, etc.), usually separating out (*gross*) loss and gain in forest cover. The FAO's FRA, which underlies much independent research, compiles country reports on *net* forest area change, grouping together forest area losses and gains. Because of this, research drawing on FAO's datasets, can only with great difficulties be compared to national GHG inventories (and still may not be comparable).

A lack of transparency in official and independent estimates of forest GHG fluxes makes it difficult to compare estimates. Efforts to reconcile GHGI reporting with independent studies requires detailed analysis of data sources, methodologies and assumptions and the ability to understand how estimates were derived. For this reason, transparency is critical for both governments and independent researchers when providing GHG estimates. In principle, GHGI reports should include sufficient information to allow for the reconstruction of estimates but, in reality, countries provide varying level of detail. For example, the DRC's discussion of land-use related GHG fluxes in its Third National Communication to the UNFCCC is only three pages long, compared with the 120 pages in the US chapter on land use (plus additional information in Annexes). Similarly, many published articles by independent researchers do not describe the approaches to GHG estimates to a level of detail that would allow reconstruction, nor provide access to the raw data that was used to derive the estimates. Without additional transparency on the methods used and calculations made, reconciliation of the data is not possible.

Forest definitions matter. Estimating GHG fluxes from forests needs to draw on a forest definition, usually chosen according to minimum area, tree height and crown cover thresholds, next to land use-related criteria. Changing any of these parameters can impact forest area estimates (see Figure below). While national GHGIs usually apply official forest definitions, independent researchers can set definitions according to practicability in data collection. Area data may also be affected by the technique of data collection and the methodology for data analysis and land representation. For example, Hansen's datasets refer to tree cover at the Landsat pixel size of 0.09 ha; for the DRC's fragmented landscape with slash-and-burn agricultural systems and patchy vegetation, it identifies forest areas about 25% higher than other sources that apply minimum mapping units closer to the official threshold of 0.5 ha as minimum area for forests. Similarly, because Hansen bases tree cover loss on changes in crown cover (including plantations), routine harvests and renewals are counted as loss and gain—which results in estimates that are not comparable to GHGI methods based on land use change.

Dependence of forest area estimates on crown cover, based on 2000 forest area extent in the University of Maryland (Hansen) dataset



Emissions from forest fires, in particular non-CO_2 emissions, are not always included in global studies that focus on changes in carbon stocks. Also, countries often use national land-based systems to detect and classify forests fires, e.g. Russia and India, compared to global datasets which use different activity data to calculate emissions from fire, such as the Global Fire Emissions Database (GFED)—which uses satellite images. Global data sets also tend to cover the entire land base (i.e. both managed and unmanaged lands).

Some countries' GHGI present opportunities for technical improvement. The case studies also support the main report's conclusion that not all developing countries capture forest-related fluxes comprehensively or accurately; hence its recommendation that improving capacity to estimate and submit more complete and more accurate GHGIs should be a priority. For example:

- The DRC's Third National Communication identifies regrowth in fallows as the single most important forest GHG flux; at 269 $MtCO_2eq$ in annual removals in 2000-2010 these are far larger than the country's total amount of emissions and removals, and underlying areas correspond to over 40 years' worth of deforestation.

- India reports only on net increases in forest area (comparable to FAO reporting) and reports a significant proportion of its net removals from the soil carbon pool. However, it seems this arises from a calculation where all the soil carbon stock from the areas with afforestation is reported as a net gain without subtracting the soil carbon stock present before the afforestation, which causes this pool to have a net C stock increase larger than all the other four carbon pools combined.

- Brazil does not report emissions from deforestation when deforested areas have been covered by clouds in the previous mapping period which results in an underestimation of total net emission from deforestation. Furthermore, such underestimation has a greater impact on more recent inventory years, potentially over estimating the decreasing trend in the time series.

In some cases, country reporting seems internally inconsistent either between data reported in different contexts or between subsequent reporting intervals. National forest statistics reported in various official country reports also appear at times inconsistent. For example, Russia's GHGI estimates, for 2015, annual net removals from forests of -608 $MtCO_2eq$, but its reporting to FAO indicates only -303 $MtCO_2eq$ of removals. Similarly, there can be discrepancies between estimates in successive reports. For example, Indonesia's first BUR explains how improvements in data collection efforts since the Second National Communication led to deforestation estimates that differ by orders of magnitude. Upgrading methodologies or underlying data requires recalculating time series to ensure consistency, but developing countries do not always do this. For example, China's first BUR in 2016 repeats the 1994 and 2005 GHGI estimates from the Initial and Second National Communications, although the forest definition was since changed.

The UNFCCC's sustained review processes have been instrumental for developed countries to build robust GHGI systems. Canada, Russia and the United States have each submitted 23 GHGI reports to the UNFCCC and benefitted from sustained feedback from the GHGI review process of National Inventory Reports (GHGIs)—which is designed to promote the provision of consistent, transparent, comparable, accurate and complete information, and to support the improvement of information submitted across subsequent review cycles[5]. Consequently, developing countries receive methodological suggestions from reviewers on how to enhance consistency and accuracy of information consistent with IPCC guidance. By comparison, Brazil, China, Indonesia and India have only recently begun to submit BURs to the UNFCCC (which undergo a technical analysis). Most other developing countries, including the DRC, have not yet had an opportunity to participate in such analysis processes. Over time, increasing participation in such processes should result in improvements in developing countries' GHGIs[6].

Better understanding of the available reports on national forest-related GHG fluxes and improving national capacities to measure such fluxes is critical in meeting the goals of the Paris Agreement. Reconciling discrepancies between independent sources and GHGI estimates could build trust in the soundness of GHGI reports. Such efforts can also help to improve national estimates and enhance their transparency. Increasing transparency and improving the understanding of national forest-related GHG fluxes will also build confidence in countries' Nationally Determined (mitigation) Contributions and the achievement of

[5] See para 5 of Annex to Decision 13/CP20 (http://unfccc.int/resource/docs/2014/cop20/eng/10a03.pdf#page=6).
[6] The scope of the current technical analysis of the BUR does not including an assessment of consistency and accuracy of information received or completeness of the GHGI; rather, the analysis is limited to transparency (See Decision 2/CP.17. Annex IV, Modalities and guidelines for international consultation and analysis, para 1 at: http://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf#page=43). A unified scope of the review process under the Paris Agreement is currently under negotiation, as part of the enhanced transparency framework.

them. It will also be critical when assessing progress towards the Paris Agreement's objectives to balance emissions and removals by the second half of the century, i.e. the Global Stocktake process.

GHGI reporting to the UNFCCC

Country	National Communications	BR or BUR	NIR	FREL/FRL	Total number of reports to date
Brazil	2004, 2010, 2016	2014, 2016	N/A	2014, 2017	7
Canada	6th in 2014	2014, 2016	2003-2017	N/A	23
China	2004, 2012	2017	N/A	--	3
DRC	2000, 2009, 2015	--	N/A	--	3
India	2004, 2012	2016	N/A	--	3
Indonesia	1999, 2011	2016	N/A	2015	4
Russia	6th in 2014	2014, 2016	2003-2017	N/A	23
United States	6th in 2014	2014, 2016	2003-2017	N/A	23

Country case studies

The Case Studies: Common points of comparison

In the case studies that follow, several common sources of information have been used to compare national GHGI estimates with other national reporting and independent analysis. These include:

Houghton, R.A. and A.A. Nassikas (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Global Biogeochemical Cycles,* 31:456-472, doi:10.1002/2016GB005546. Country level data were developed in the article cited (but unpublished). Hereafter referred to as "Houghton" data.

Country reports to the FAO's Forest Resource Assessment (FRA), from which forest flux estimates may be derived, i.e. using Federici, S. et al (2015). New estimates of CO2 forest emissions and removals: 1990-2015. *Forest Ecology and Management,* 352, pg 89-98. Hereafter, emissions and removal estimates derived from the FRA country reports are referred to as "FRA" estimates.

Global Forest Watch – Climate, from: climate.globalforestwatch.org (referred to as "GFW"), combines data from:

- Hansen, M.C. et al (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science,* 342: 850-853. The data from the 2013 study has been updated to 2015 and can be found online at: http://earthenginepartners.appspot.com/science-2013-global-forest. Hereafter referred to as "Hansen" data.
- Baccini, A. et al (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*, 2: 182-185.

Note: Figures are often referred to as "MtCO2" or "Mha" which refer to million tons or hectares.

Brazil

As of 2010, Brazil was ranked as the 7th largest GHG emitter in the world[7], with deforestation as its largest source of emissions across time. According to FRA 2015, Brazil has the second largest forest area in the world (12.3% of the global forest area), including the largest tropical forest, the Amazon. Forest covers 57.9% of the total national territory, and is continuously decreasing from 546.7 Mha (64.2%) in 1990, to 521.3 Mha (61.2%) in 2000, to the current cover of 493.5 Mha[8].

In 2004, Brazil established and implemented the Action Plan for the Prevention and Control of Deforestation of the Legal Amazon[9] (PPCDAm), and in 2010 launched the National Policy on Climate Change that included goals for the reduction of deforestation in both the Legal Amazonia and the Cerrado biomes. Brazil has a robust civil society that closely monitors the country's forest loss and emissions data and publish an independent GHG inventory, including for forest-related categories[10]. Together, these actions contributed to reducing the rate of forest loss in Brazil.

The 3rd National Communication of Brazil contains the most up to date GHGI of Brazil. It covers all C pools for all forest-related GHGI categories (NF→F, F→F, F→NF). Brazil is one of the few developing countries that applies the IPCC's managed land proxy and separates managed forest land (235 Mha) from unmanaged forest land (258 Mha). It therefore provides estimates for GHG emissions and removals on managed lands, while assuming that GHG fluxes on unmanaged land is predominantly caused by natural factors, and hence are not reported (although unmanaged land is monitored).

Comparing the GHGI estimates with those of three alternative government and non-official information sources: FRA, SEEG and Houghton, there is good agreement among the GHGI, FRA and SEEG on total GHG net emissions across the period 1994-2010 (including managed forest land as a net sink and deforestation as a net source larger than the managed land sink) since these are largely based on the same datasets. Houghton estimates of net emissions are significantly lower than the other sources (by about 25%), likely due to the difference (as suggested in the main report) in defining "what is anthropogenic".

Data on gross deforestation, however, show large differences among the national GHGI, FRELs and Global Forest Watch (GFW). Some differences are due to the use of different emission factors, i.e. the use of various data sources and methods applied to derive C stocks from those data sources. There are also differences in the sources and methods used to estimate activity data that explain why estimates may not be comparable and result in significant disparities. For instance, although GFW estimates include tree cover losses in forest and non-forest land, the total gross "deforestation" is smaller than that reported in the GHGI and FRELs; or, the GHGI does not report a large reduction in emissions from deforestation, unlike REDD-plus related reporting. Such differences are further explained in the sections that follow.

It is expected that accounted results in the NDC will be different from those accounted for in REDD-plus due to differences in the level and trend of GHG emissions estimates as reported in the GHGI and REDD-plus reports, as well as the use of different reference levels.

[7] https://www.transparency-partnership.net/wri-2015-visualizing-most-recent-global-greenhouse-gas-emissions-data
[8] Data from FAO FRA 2015 - http://www.fao.org/3/a-az172e.pdf
[9] The Legal Amazon encompasses nine states: Acre, Amazonas, Amapá, Maranhão (totally included since May 2008), Mato Grosso, Rondônia, Pará, Roraima and Tocantins, with a total of 5.02 million km^2. It incorporates the entire Amazon biome (4.21 km2) and parts of the Cerrado and the Pantanal biomes.
[10] http://seeg.eco.br/en/ SEEG. 2016. Evolução das Emissões de Gases de Efeito Estufa no Brasil (1990-2015). Sistema de Estimativas de Emissões de Gases de Efeito Estufa (SEEG).

Brazil's reporting under the UNFCCC

Brazil has submitted three National Communications (NC) and two Biennial Update Reports (BURs). The latest complete GHGI of Brazil has been submitted in the 3rd NC (April 2016).

Brazil is active in the implementation of the REDD-plus for results-based payments. In 2014, Brazil was the first country to submit to the UNFCCC a FREL for the Amazon biome[11], followed by submission of the associated results for the periods 2006-2010 (in a technical annex to the 1st BUR, 2015) and 2011-2015 (2nd BUR, March 2017). In 2017, it submitted a FREL for the Cerrado Biome[12], for the period 2011-2020. It has also submitted its REDD-plus strategy and summary of information on how REDD-plus safeguards have been addressed and respected.[13] The FREL and related results (2006-2010) for the Amazon biome have been subject to review (technical assessment of FREL in 2014, and technical analysis of the results in 2016). The FREL for the Cerrado is presently under technical assessment.

Brazil has technical capacity to monitor and report GHG emissions and removals from forest land and is often referred to as a global leader in forest observation[14]. Although, given the resources available, ground data collection on such a large area remains a challenge. Presently, the country is implementing its First National Forest Inventory, coordinated by the Brazilian Forest Service of the Ministry of the Environment.

Methods and some background data applied for preparing the GHGI are further described in the Reference report: "Setor Uso da Terra, Mudança do Uso da Terra e Florestas"[15].

What forest fluxes are included in the GHGI?

Forest definition and managed land proxy: The Brazilian forest definition applied in the GHGI does not use quantitative thresholds (for example, those used in the FAO definition of forest); forest land is rather characterized by a tree density that reduces the amount of light that reaches the soil thereby limiting the development of bushes and grasses. When identifying forest area changes in Amazonia and the Cerrado, Brazil considers the official Vegetation Map from IBGE, which was the basis for the forest "mask" used in PRODES (in addition to other elements in the satellite imagery). PRODES provides estimates of conversion of forests to other land categories using data from TM-Landsat-5 (30 meter resolution), LISS-III/Resourcesat-1 (23.5 meters), and CBERS-4 (25 meters), with minimum mapping area of 6.25 ha (scale 1:250,000) and minimum tree cover density of 20%. These parameters have been maintained since the beginning of the deforestation time-series for Amazonia, but other projects identify areas of deforestation less than 6.25 ha.

[11] In the Amazon Biome, Brazil launched in 2004 and implemented since 2005 the PPCDAm; this suggests that data on deforestation before 2005 may represent the deforestation rate expected in absence of the implemented action plan, i.e. the BAU scenario to calculate the FREL.

[12] For the Cerrado biome, the National Policy on Climate Change, set by Law No. 12,187 of December 29, 2009 and regulated by Decree No. 7,390 of December 9, 2010 establishes, among the mitigation activities planned up to 2020, a 40% reduction in the rate of gross deforestation compared to the average annual deforestation observed between 1999 and 2008; this suggests that data on deforestation before 2008 may represent the deforestation rate expected in absence of the implemented policy, i.e. the BAU scenario to calculate the FREL.

[13] All information available at: http://redd.unfccc.int/submissions.html?country=bra

[14] Rajao et al (2017), Table 1; DEGRAD is mapping degradation of forest cover in Primary forest since 2007, it uses same images used for PRODES.

[15] http://sirene.mcti.gov.br/documents/1686653/1706165/RR_LULUCF_Mudança+de+Uso+e+Floresta.pdf/11dc4491-65c1-4895-a8b6-e96705f2717a

Since its 2nd NC, Brazil used the 2003 IPCC GPG for LULUCF, improved in the 3rd NC with the use also of the 2006 IPCC Guidelines, where appropriate. Consequently, Brazil applies the managed land proxy[16]. This means that the GHGI does not include GHG emissions and removals from forest land classified as unmanaged forest, although their conversion is immediately reported, as all forest conversions are assumed to be caused by human activities.

Unmanaged and managed forest area by biome in 2010, as reported in Brazil's 2010 GHGI

Biome	Unmanaged (Mha)	Managed (Mha)	Total (Mha)
Amazon	130.5	189.2	319.7
Cerrado	60.2	18.4	78.6
Caatinga	39.6	11.4	51
Atlantic Forest	17.9	14.9	32.8
Pampa	2.1	0.8	2.9
Pantanal	8.1	0.5	8.6
TOTAL	258.3	235.3	493.6

The managed forest land is subdivided in 4 subcategories:

1. *managed forest*, that includes all indigenous forest reserve and any other conservation sites;
2. *secondary forest*, that includes all forest regrown after the primary forest was cleared;
3. *reforestation*, that includes all forest plantations (mainly *Eucalyptus* spp and *Pinus* spp);
4. *selective logging*, that includes areas where the tree cover is reduced but land is not converted to other land use (such category is reported for the Amazon biome only, through DETEX[17]).

An additional forest category whose area is quantified and reported is *unmanaged forest* (land that does not conform to the definition provided in footnote 12) where GHG emissions and removals are not reported although the land is continuously monitored.

Forest-related categories: The GHGI includes GHG estimates for the periods 1994-2002 and 2002-2010, except for the Amazonia biome, where estimates are provided for the periods 1994-2002, 2002-2005 and 2005-2010, for all forest-related land categories, NF→F, F→F, F→NF, as well as for all conversions among forest land subdivisions (GHGI, Tables 3.81-3.110) disaggregated by biome. Consequently, the land representation estimates all conversions from and to forest and from and to each forest land subdivision applying a wall-to-wall IPCC Approach 2[18] using maps prepared for the years 1994, 2002 and 2010; for the

[16] The 3rd NC reports: "In the case of Brazil, Managed Land comprises the entire area contained in Indigenous Lands – according to information provided by the National Indian Foundation (FUNAI), whose processes of demarcation are minimally in the "Delimited" phase – in state and federal protected areas – according to the Ministry of the Environment (MMA) and the National System of Protected Areas (SNUC), Law 9985/2000, except for the Private Reserves of Natural Preservation (RPPN) due to the lack of consistent information about them. Data on forest areas and associated GHG emissions/removals reported in the GHGI are disaggregated by the following land categories: Managed forests, Secondary forests, Reforestation, Secondary forests, Forest subject to selective logging, and all the land conversion categories from unmanaged forests to those types of forest and among those type of forest (although GHG emissions/removals in land of reforestation remaining reforestation are not report). No definitions for the listed forest types are reported in the GHGI.

[17] System for Monitoring the Selective logging (Detex); the main purpose of the program, developed by INPE in conjunction with the Brazilian Forest Service (SFB), is to monitor the actual implementation of management plans in forest concessions and public forests.

[18] This is Approach 2 because areas of changes are not tracked across time so that subsequent changes are classified as belonging to areas previously subject to change. E.g. a forest land converted to grassland and thereafter converted to forest land before the end of the transition period is classified first as forest land converted to grassland (same would occur for approach 3) and thereafter as grassland converted to forest land, while applying approach 3 it should be as a subdivision grassland converted to forest land, e.g. "Forest land converted to grassland). Tracking the historical changes of a land has an impact on the C stock change estimates. In the example, the SOC of the grassland at second

Amazon biome an additional map of the year 2005 has been used. The results of verification of the maps used for the land representation are reported for each biome[19]. Although the accuracy of maps may appear high, it does not indicate accuracy of land use *changes* across maps.

The Brazilian land representation includes an additional land use category for areas that have not been classified (identified in the inventory as "NO", not observed), largely due to cloud cover. GHG emissions and removals from areas remaining in the NO category as well as from areas converted to and from the NO category are not estimated (e.g. a forest area in 1994 that is cloud-covered in 2002 and subsequently a grassland in 2010 is not reported as deforested and GHG emissions and removals are associated with such land-use change). By comparing areas of forest land conversions to NO in a time period, and of NO conversions to forest land categories in a subsequent time period, it is possible to identify additional areas of deforestation. For instance, in Table 3.83 the total area of forest categories converted to NO adds to 17.3 Mha (Amazon biome 2002-2005), while in table 3.84 (Amazon biome 2006-2010) the total area of NO converted to forest land categories sum up to 13.8 Mha. This means that an additional 3.5 Mha were deforested in the period 2002-2005[20]. An estimate can be made for the period 2006-2010 by assuming a similar rate of conversion for the period 2002-2005. It should be noted (see Annex IIa, Table 6) that the use of the category NO has introduced a trend in the GHGI estimates since the category is almost not used in the period 1994-2002 while it is significantly used[21] in the period 2002-2005, especially in the Amazon Biome.

The GHGI therefore reports annual C losses for the conversion from forest to non-forest land as well as from non-forest land to forest land; and from a forest type to another forest type (except for conversion of *unmanaged forest* to *managed forest*, since the conversion implies a change in the legal status of the land only, not in the C density). The C stocks of biomass and DOM are assumed to be completely lost during the forest conversion process, except in the following situations: (a) conversion of forest types to selectively logged forest (where the C loss is calculated as the difference between the average C stock of the previous forest type and the fraction of C stock remaining in the selectively logged forest); (b) conversion of selectively logged forest to secondary forest where no C stock losses are estimated (this is considered as an abandonment process); and (c) conversion of forest land to grassland, settlements or other land, where the C loss is calculated as the difference between the average C stock of the previous forest type and the average C stock under the current land use. No C stock losses are reported in forest land where the forest type does not change, except in the case of selective forests[22]. This means that C stock losses associated with harvest and disturbances that do not determine a land use change or a change in the forest type are not estimated.

Annual C gains[23] for all managed forest types are estimated using increment rates from research papers[24]. For plantation the C gain is estimated from the first plantation to the end of its first cultural cycle only (7

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conversion would not be equivalent to the average SOC of grassland, as it would result from the SOC of forest decreased across the conversion period until the point of the new conversion.

[19] See Table 2 of "Setor Uso da Terra, Mudança do Uso da Terra e Florestas" http://sirene.mcti.gov.br/documents/1686653/1706165/RR_LULUCF_Mudança+de+Uso+e+Floresta.pdf/11dc4491-65c1-4895-a8b6-e96705f2717a

[20] It can be assumed that the deforestation occurred at equal annual rate across the period.

[21] In Annex IIa, Table 6 we estimated, for the time period 2002-2010, an area of 7.9 Mha of deforestation whose associated GHG emissions have not been estimated since classified as forest conversion to NO. For the time period 1994-2002, such misclassification affects only 0.04 Mha.

[22] In selective forests (reported only for the Amazon Biome) the annual net increment is assumed to be 0.02% of the growing stock; which is assumed to be 44% of the stock in primary forests although the harvesting C loss is assumed to be equivalent to 29% of the average stock (within a planned management system, this corresponds to a rotation period of 18 years).

[23] As with other developing countries, there is no explicit treatment in Brazil's land use inventory of age class (or other parameter of C density distribution) for estimating C stock gains in forest land.

[24] Third National Communication of Brazil, Table A1.18 (page 293) and Table A1.19 (page 295).

years for *Eucalyptus spp* or 14 years for *Pinus spp*), thereafter the plantation is assumed to be at equilibrium, i.e. C losses equal C gains across the following cultural cycles. However, increment factors are applied to all *managed forest* and *secondary forests,* in effect resulting in a continuous carbon accumulation (without taking into account the limited storage capability of C pools) across the entire time series[25]. Removals from other subdivisions of forest land are also reported using a constant and continuous net increment. This methodological approach is unbalanced since all C stock gains are estimated but not all C stock losses and evidence is not provided to clarify whether the approach accurately reflects actual net C stock change in the Brazilian forests.

Pools: The GHGI estimates all five C pools (above and below ground biomass, litter and dead wood, soil organic matter in mineral soils). It does not include emissions from drained organic soils,[26]

Gases: Non-CO_2 GHGs are estimated only for biomass burning associated with deforestation. In an appendix, the GHGI reports preliminary emissions from fires in forest and grassland (not associated with deforestation) for the year 2010 of 269 $MtCO_2eq$ (using GWP from AR5 for CH_4 and N_2O); a magnitude equivalent to the net sink reported in forest land remaining forest land; therefore, its future inclusion in the national GHGI may significantly change the total reported GHG flux from forests.

<table>
<tr><td colspan="4">Forest-related category coverage in Brazilian submissions to UNFCCC</td></tr>
<tr><td></td><td>F > NF</td><td>F > F</td><td>NF > F</td></tr>
<tr><td rowspan="2">3rd NC (2016)</td><td>Estimates land use conversion from forest to other land use categories using satellite imagery (mainly Landsat) and constant factors of C stock change stratified by Biome and by vegetation type. Non-CO2 emissions from forest fires resulting from deforestation included.</td><td>Estimates use annual increment rates. Losses are estimated for conversion to selectively logged forests (Amazon only) and to secondary forests and to plantations, by applying constant factors. GHG emissions from forest fires are estimated but only included in an appendix.</td><td>Estimates use annual increment at constant rates. Losses of previous vegetation are estimated by applying constant factors.</td></tr>
<tr><td colspan="3">Data to calculate factors for each C pool are taken from research projects and IPCC defaults</td></tr>
<tr><td>Amazon FREL (2014)</td><td>Primary forest cover loss[27] only, estimated using Landsat imagery. C stock factors (consistent with those used in the 2nd NC) derived from research or applying IPCC default factors.</td><td>Not included</td><td>Not included</td></tr>
<tr><td>Cerrado FREL (2016)</td><td>Natural forest cover loss only, estimated using Landsat imagery. C stock factors from 3rd NC used.</td><td>Not included</td><td>Not included</td></tr>
</table>

Considering that Brazil is reporting a sink in indigenous forest reserves (classified as managed forest), and that these forest reserves differ from unmanaged forest only in their legal status, there is a high likelihood

[25] Also secondary forests on former cropland and grassland are reported with constant and continuous growth with a rate of 2.85 t C/ha, in former pasture, and 4.73 t C/ha in former cropland; while in former non-agricultural areas, e.g. former mines, is 0.59 t C/ha constant and continuous growth is reported.
[26] Peatlands in Brazil are estimated to cover around 5.5 Mha of which 5 Mha are forested (the largest in any South American country); https://unfccc.int/files/kyoto_protocol/application/pdf/draftpeatlandco2report.pdf
[27] The 2003 IPCC GPG for LULUCF and 2006 IPCC Guidelines defines deforestation as the sum of land use changes from forest land to any other land use category. This means that deforestation implies a change in land use while the Brazilian methodology defines deforestation as forest cover loss without consideration of whether the loss would be followed by forest regrowth. This inconsistency with IPCC methods may explain differences in the GHG estimates between the FREL and national GHGI.

that the 254.3 Mha of Brazilian unmanaged forests are an additional sink of –287.6 Mt CO_2 in 2010. However, a significant decrease of around one-third[28] of such a natural sink in the biomass of the Amazon biome has been reported and a further decrease is expected because of an increase in mortality rate (Brienen et al, 2015); although if the increasing mortality is resulting in an increasing long-term average C stocks in DOM and SOM these would also be accounted for as an additional sink.

Uncertainties of GHG estimates have been estimated by applying the IPCC default approach for error propagation reported for the aggregated LULUCF sector as: ±32% for CO_2, ±72% for CH_4, and ±101% for N_2O. No additional information is reported on uncertainty of data and parameters used and on uncertainties calculated for each category, subcategory and subdivision.

Comparison of national reporting to independent studies

The following table summarizes the total GHG net emissions/removals from the three forest-related categories (F→F, NF→F, F→NF), as reported by Brazil in its 3rd NC[29], those calculated by FAO[30] from data submitted by Brazil to FRA, estimates by Houghton and Global Forest Watch (GFW), those estimated by the Brazilian Independent Climate Observatory Initiative in its System Study Greenhouse Gas Emissions Estimates (SEEG)[31]; and the GHG net emissions from deforestation estimated by the Global Forest Watch.

Year 2010 annual GHG fluxes for forest -related categories							
Source	F→F	NF→F	F→NF	Other	Total	C pool	GHG
	Mt CO_2eq yr^{-1}						
GHGI 3rd NC	-280.4 (–568.0)	-98.7 (-101.8)	1,318.5 (1,684.2)	- (268.6)[32]	939.4 (1,283)	AGB, BGB, DOM, SOM (mineral soils only)	CO_2, (CH_4, N_2O)
FAO FRA[33]	-430.8 [-204.5]	-201.7** [-118.7]	1,433.9** [843.8]	-	801.3 [520.6]	AGB, BGB, DOM, SOM[16]	CO_2,
SEEG	-410.0	-113.8	883.7	-	359.9	AGB, BGB, DOM, SOM[16]	CO_2, CH_4, N_2O
Houghton 2017	106.2	112.7[34]**	611.6**	-	830.6	AGB, BGB, DOM, SOM[16], HWP	CO_2
GFW[35]	-	-	792	-	-	AGB, BGB	CO_2
* Values in parenthesis have been estimated by allocating areas of category NO to NF→F, F→NF, and, in F→F, and the additional sink in unmanaged forest land ** net forest area change							

Although the estimates of the GHGI, FAO FRA, SEEG and Houghton have been derived using similar datasets provided by Brazilian institutions, different methodological approaches result in significantly different GHG estimates. For example, the GHGI and FRA estimates are averages across time periods of 8 and 5 years, respectively. Although FRA does not include non-CO_2 emissions and uses net area loss as activity data, its emissions from deforestation are higher than those reported in the GHGI (that includes non-CO_2 emissions and gross forest cover area loss as activity data). GFW and SEEG estimate emissions

[28] From almost 0.65 t C ha^{-1} yr^{-1} in 1990 to 0.45 t C ha^{-1} yr^{-1} in 2010 (visual interpretation of Figure 1 of the paper cited.
[29] 2016 (available at http://unfccc.int/resource/docs/natc/branc3v3.pdf)
[30] 2015 (available at http://www.fao.org/3/a-i4895e/i4895e09.pdf)
[31] 2016 (available at http://seeg.eco.br/en/)
[32] Emissions from forest fires not associated with deforestation
[33] Biomass pools only
[34] It corresponds to forest plantations only
[35] Annual gross carbon emissions (WHRC/Baccini et al. 2015). Selected tree cover threshold > 10%

from deforestation using annual data, which makes them more comparable, and the difference between them may be explained by the different C pools and gases included.

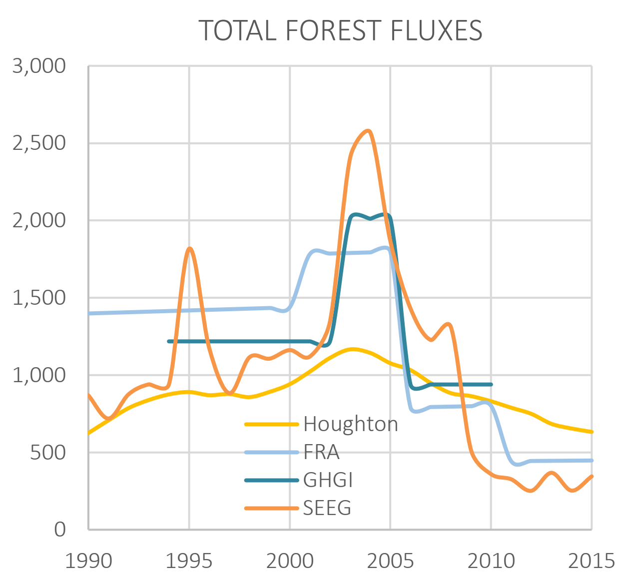
The higher sink in FRA estimates of afforested areas can be explained by the method applied, i.e. accounting as a net increase the entire average C stock of a forest land in the year in which the land is converted to forest. However, methodological differences for the higher sink in F→F are not apparent. Although most estimates report a net sink in F→F and NF→F, Houghton reports a net source since its methodology excludes CO_2 removals assumed to be non-anthropogenic (i.e. uptake in forests outside of harvested areas).

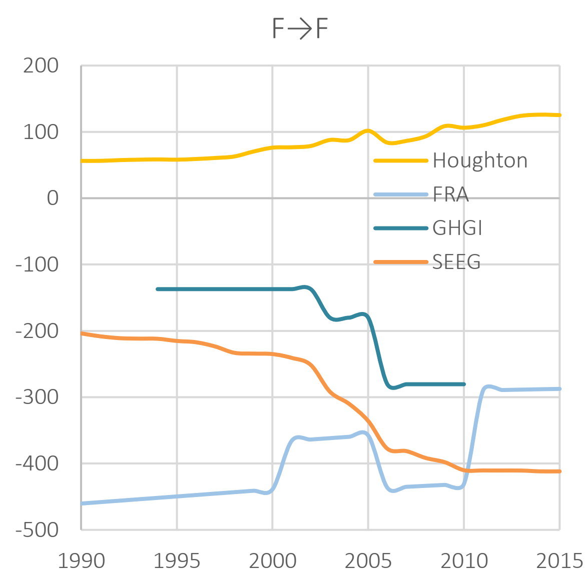
Finally, it is notable that although there are varying methodological differences, different sources provide a very close estimate of total GHG net emissions from forest land (including deforestation) for the period 1994-2010 (see following table), except for Houghton's estimates.

All figures in MtCO$_2$eq	FRA	GHGI	SEEG	Houghton
1994-2010	22,911.8	21,692.8	22,351.3	16,282.2

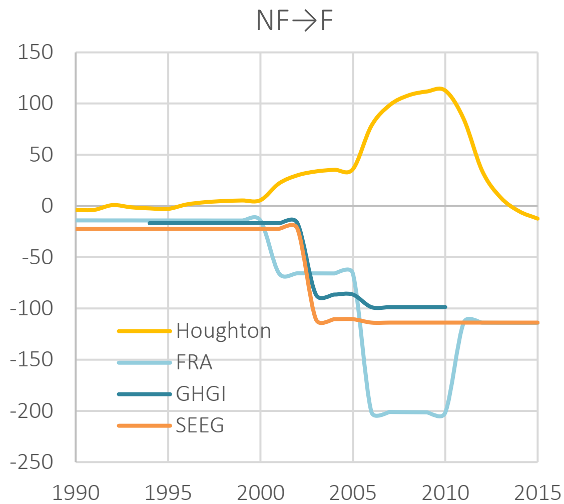
Considering that Houghton's estimates do not include a large portion of CO_2 removals in forest land, it is expected that the net emissions estimated by Houghton would be higher than those estimated by the other three studies. Another potential difference could be in how HWPs, which are a likely sink, are estimated in conjunction with a large under-estimation of GHG emissions from harvesting and the exclusion of emissions from fires associated with deforestation.

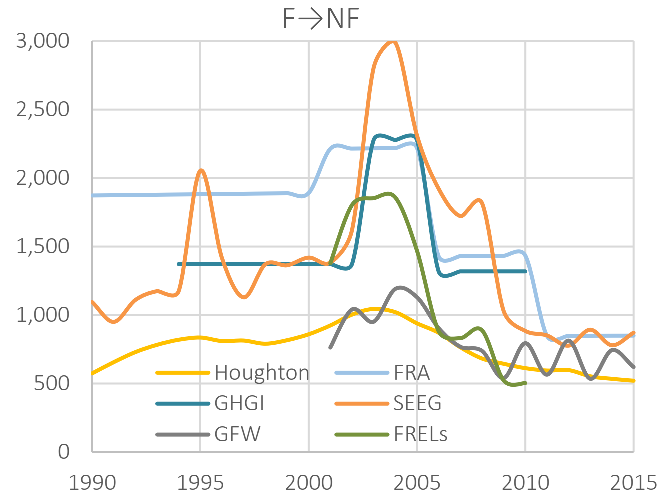
Below is a comparison of time series of GHG fluxes (MtCO$_2$eq) for each forest-related category as reported by Houghton, GHGI, FRA, SEEG, GFW and as a sum of FRELs (Amazon and Cerrado biome)[36].





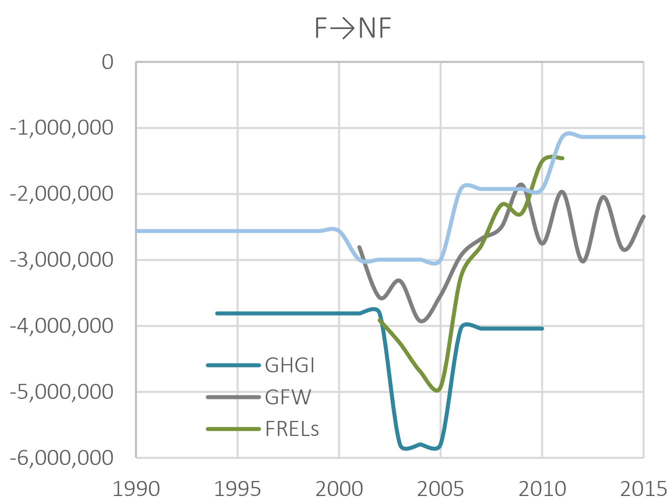
[36] The two biomes cover 80% of the total Brazilian forest area.





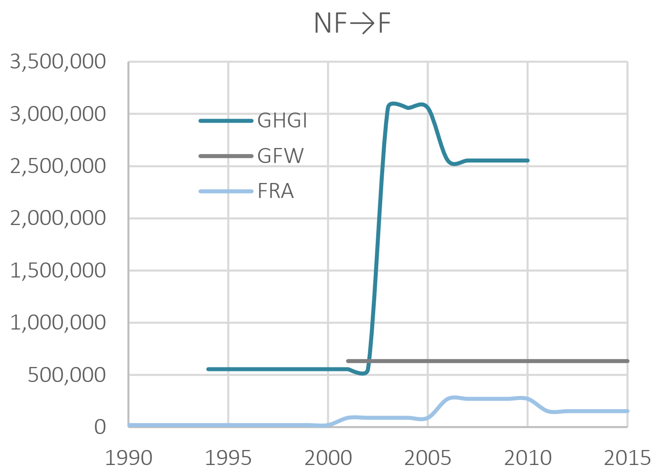
Between the time periods 1994-2005 and 2006-2010, the GHGI reports a change in net emissions from deforestation of 1.6 $GtCO_2eq/yr$ to 1.3 $GtCO_2eq/yr$, or a nearly 20% decrease (see Annex IIb, Table 1). Although, if the potential contribution of forests conversions to/from the NO category is included, net emissions from deforestation can be assumed to have decreased from 1.8 $GtCO_2eq/yr$ to 1.7 $GtCO_2eq/yr$ or -5.5% (see Annex IIb, Table 2).

The GHGI reports a significantly larger amount of emissions from deforestation than GFW, even though GFW includes in its estimates all tree cover losses (in forest and non-forest land, temporary losses and permanent losses) while the GHGI only reports permanent losses of forest cover. GFW also reports lower emissions than estimates provided in the FREL submissions, even though FRELs only include forest cover losses in primary/natural forests in a portion of the Brazilian territory while GFW includes all tree cover losses (in forest and non-forest land) across the entire country. As shown in Figures below, such differences in GHG emissions are driven by differences in cleared area estimates[37]. The figures compare time series of area (ha) as reported by GHGI, FRA, GFW and as a sum of FRELs (Amazon and Cerrado).[38]



- ✓ For F→NF:
  - o GHGI reports gross deforestation;
  - o FRA reports net deforestation
  - o GFW reports gross tree cover loss
  - o FRELs report gross forest cover loss (of Primary/Natural forests)

[37] The Amazon FREL and the GHGI for Amazon use biomass C stocks of forest land derived from the RADAMBRASIL dataset (although, the FREL and GHGI apply different expansion factors and different methodologies for data spatialization). The Cerrado FREL has been calculated applying same C stock factors applied for the GHGI.
[38] The 2 biomes cover 80% of the total Brazilian forest area.



- ✓ For NF→F:
  - GHGI reports gross afforestation;
  - FRA reports net afforestation
  - GFW reports gross tree cover gain

Although the GHGI uses the same images as PRODES[39], methodological differences result in differences in estimated deforestation rates. This is potentially due to different methods of image analysis—while PRODES collects data annually through visual delineation of deforested areas in satellite images, the GHGI methodology collects periodic[40] data through segmentation (i.e. semi-automatic stratification in homogeneous land cover units) of image mosaics in land use areas, and subsequent identification of deforested areas through overlapping maps. It may also be due to different targets—PRODES estimates gross cover loss of primary forest only, which means that deforestation of secondary forests is not detected; this results in an increasing[41] bias (i.e. systematic underestimation) of total deforested area[42]; PRODES also treats temporary forest cover losses as permanent losses since the land cover is not tracked further, which also results in bias (i.e. systematic overestimation) of total deforested area, which may be decreasing[43] so far as farmers are incentivized to sustainably manage their lands to preserve long-term fertility. In contrast, the GHGI estimates deforestation as land use conversion from forest land categories to non-forest land categories. The GHGI also estimates the subsequent regrowth of forest or of the vegetation that has replaced forest.

Differences between 3rd GHGI and PRODES Amazonia estimates of deforestation rate (from 3rd NC)

Element	3rd NC - GHGI	PRODES
Spatial scale	1:250,000	1:75,000
Spatial coverage	All Brazil territory	Legal Amazon only
Objective	Any land cover	Primary forest only
Cloud cover	replacement of images with high cloud cover[44][45]	adjusted increments of deforestation-

[39] The calculation of the Amazon FREL for REDD-plus is based on PRODES (Gross Deforestation Monitoring Program in Amazonia) of INPE (Brazilian National Institute for Space Research), adapted to include only forest physiognomies in the Amazonia biome. PRODES detects annual forest cover losses (clear cut) in Legal Amazon in areas classified as Primary forest (Primary Forest in year 1987 minus all areas clear-cut from 1987 onward).

[40] Of three years (1994,2002,2010) across the time series, and classification in land use classes

[41] This is because the area of secondary forests is increasing across time.

[42] This effect has been noted for instance in "Are Brazil's Deforesters Avoiding Detection?" a paper in Conservation Letters of Richards et al – 2016. In that paper the authors notes that out pf the 900,000 ha of deforestation not detected by PRODES as compared to GFC and FIRMS, 250,000 ha occur in secondary forests.

[43] Clear cut has been almost abandoned as harvesting techniques

[44] As for actions contained in PPCDAm. i.e. the Plan to Prevent and Control Deforestation of the Legal Amazon

[45] Out of 198 images, 91 in 2005 and 54 in 2010 have been replaced because of high cloud cover

Deforestation identified as	conversion of any forest subcategory to other land cover categories	complete loss of tree cover in Primary forest
Forest area in the Amazon biome	319,656,558[46] ha	380,095,600 ha
Deforestation 1994-2010 in the Amazon Biome (cumulative)	32,988,269 ha[47]	29,352,100 ha[48][49]

The difference in the cumulative deforested area suggests the importance of the loss of secondary forests that PRODES does not cover by definition, i.e. the GHGI reports 12% more deforestation than PRODES. Further, PRODES data covers the Legal Amazon[50], which is larger than the Amazon Biome and therefore about 12% of deforestation reported by PRODES does not occur in the Amazon Biome. Furthermore, the GHGI omits from its deforestation those forest areas reported first as converted to the NO category and thereafter reported as NO land converted to other land uses (see Annex IIa, Table 6). Therefore, in sum, the deforested area reported by GHGI may be estimated as 54% larger than the area reported by PRODES.

The FREL for the Amazon Biome is based on PRODES data, although with an adjustment for deforested areas that were covered by cloud in the year(s) previous the year in which deforestation is detected. In PRODES, deforestation in areas that were under cloud cover in the year(s) prior to the year of detection is entirely attributed to the detection year. For the FREL calculation, deforestation is apportioned in equal fractions[51] to the contiguous years in which was under cloud cover just before deforestation. This adjustment procedure results in a backward shift along the time series of deforested areas, lowering deforestation in the "results" periods of 2006-2010 and 2011-2015 compared to PRODES data. It may also explain (see table below) discrepancies in annual data between PRODES and the FREL time series of deforested land. In particular, it likely explains why the total area reported as deforested in the FREL time series (1996-2005) is larger than that reported in the PRODES time series even though the PRODES data includes other areas of deforestation occurred outside the Amazon Biome (but within the Legal Amazon). The difference in total deforested area of PRODES and FREL shows a decreasing trend[52] that is due by the fact that the backward shift of deforestation areas due to the adjustment procedure determines a decreasing gradient[53] from the high end (i.e. oldest years) of the FREL time series, where the adjustment is likely to have resulted in a net addition[54] of areas, to its low end[55].

[46] Estimated from data on Amazon for the year 2010 contained within Tables 3.81-3.110 (3rd NC)
[47] Estimated from data on Amazon contained within Tables 3.81-3.110 (3rd NC)
[48] From http://www.obt.inpe.br/prodes/prodes_1988_2016n.htm
[49] This includes deforestation in all Legal Amazon; according to the Amazon FREL submission (page 13), 12% of the total deforestation registered in Legal Amazon does not occur in the Amazon Biome.
[50] It includes all Amazon Biome, 37% of Cerrado Biome and 40% of Pantanal Biome
[51] This means that the area deforested is divided by one plus the number of years in which the land where the deforestation occurred has been under cloud cover and therefore not analyzed e.g. if the area deforested e.g. 1,000 ha was under cloud cover in the previous 3 years a quota of 250 ha (1,000/4) has been allocated to each of previous three years and to the current year.
[52] While in the period 1996-2005 the area included in the FREL is significantly larger (+1.5 Mha) than the area detected by PRODES, in the accounting periods (2006-2010 and 2011-2015) the area included in the FREL is significantly smaller than the area reported by PRODES
[53] The gradient may determine to account for a deviation of 20-25% from the historical reference level, in the accounting periods 2006-2010 and 2011-2015,
[54] E.g. in the years 1996-2000 the FREL time series reports a larger deforested area than PRODES because some areas reported by PRODES in the following years, e.g. 2004, have been added to the FREL time series as consequence of the adjustment procedures. While it is unclear if some areas have been subtracted from the FREL time series 1996-2000 since assumed to have occurred in older years external to the time series (e.g. 1991-1995.
[55] A complete publication of the calculation of adjusted deforestation rates would clarify the issue.

	PRODES (Legal Amazon)	FREL (Amazon Biome)	Comparison FREL vs PRODES	FREL emissions $MtCO_2/yr$	3rd NC GHGI (Amazon Biome)		FREL emissions	GHGI emissions
	hectares (deforestation)				area (ha)	Mt CO_2/yr	$tCO_2/ha/yr$	
1996	1,816,100	1,874,013	3%	980	1,946,480	1,007	523	517
1997	1,322,700	1,874,013	29%	980	1,946,480	1,007	523	517
1998	1,738,300	1,874,013	7%	980	1,946,480	1,007	523	517
1999	1,725,900	1,874,013	8%	980	1,946,480	1,007	523	517
2000	1,822,600	1,874,013	3%	980	1,946,480	1,007	523	517
2001	1,816,500	1,949,331	7%	909	1,946,480	1,007	466	517
2002	2,165,100	2,466,604	12%	1,335	1,946,480	1,007	541	517
2003	2,539,600	2,558,846	1%	1,375	3,274,506	1,705	537	521
2004	2,777,200	2,479,430	-12%	1,380	3,274,506	1,705	557	521
2005	1,901,400	2,176,226	13%	1,164	3,274,506	1,705	535	521
2006	1,428,600	1,033,634	-38%	576	1,518,581	745	557	491
2007	1,165,100	1,087,469	-7%	608	1,518,581	745	559	491
2008	1,291,100	1,233,038	-5%	666	1,518,581	745	540	491
2009	746,400	596,374	-25%	364	1,518,581	745	611	491
2010	700,000	583,148	-20%	344	1,518,581	745	591	491
2011	641,800	501,406	-28%	286				
2012	457,100	425,500	-7%	237				
2013	589,100	537,857	-10%	302				
2014	501,200	490,851	-2%	274				
2015	620,700	524,057	-18%	288				
sum (1996-2005)	19,625,400	21,000,503	7%	11,060	23,448,882	12,162		
sum (1996-2010)	24,956,600	25,534,164	2%	13,619	31,041,789	15,888		
sum (1996-2015)	27,766,500	28,013,836	1%	15,005	-	-		
sum (2006-2010)	5,331,200	4,533,662	-18%	2,559	7,592,906	3,727		
sum (2011-2015)	2,809,900	2,479,672	-13%	1,385	-	-		

Further, per hectare emissions in the FREL are larger than those reported in the most recent GHGI (although are more comparable to estimates provided in the 2nd NC). Although one may expect the opposite given the FREL does not include dead wood and SOM pools, nor non-CO_2 GHG from fires. The per hectare emissions from deforestation reported by GFW are 285 $tCO_2/ha/yr$, or 56% and 53% lower than those reported by the FREL and GHGI, respectively.

For the Cerrado, the activity data for deforested areas were estimated from the analysis of the Landsat-5 satellite images, with 30x30 meter spatial resolution covering the entire biome (wall-to-wall). The year 2000 was defined as the reference year for identifying and mapping, through visual interpretation, new polygons of deforestation in the following periods: 2000-2002; 2002-2004; 2004-2006; 2006-2008; and 2008-2010. The entire thematic mapping process is performed using the interpretation scale of 1:75,000.

Year	FREL (Cerrado Biome)* area (ha)	FREL (Cerrado Biome)* t CO_2 yr^{-1}	3rd NC GHGI (Cerrado Biome) area (ha)	3rd NC GHGI (Cerrado Biome) t CO_2 yr^{-1}
2001	2,098,155	468,466,023	1,049,174	200,573,988
2002	2,098,155	468,466,023	1,049,174	200,573,988
2003	2,151,777	478,153,156	1,259,048	242,980,825
2004	2,151,777	478,153,156	1,259,048	242,980,825
2005	1,356,658	306,070,255	1,259,048	242,980,825
2006	1,356,658	306,070,255	1,259,048	242,980,825
2007	1,000,721	222,589,427	1,259,048	242,980,825
2008	1,000,721	222,589,427	1,259,048	242,980,825
2009	759,913	158,083,682	1,259,048	242,980,825
2010	759,913	158,083,682	1,259,048	242,980,825
sum (2001-2010)	14,734,448	3,266,725,086	12,170,732	2,344,994,575
average	1,473,445	326,672,509	1,217,073	234,499,458

**Figures may change in a modified FREL submission for the Cerrado biome.*

Differences in the amount of deforested area have been explained, in the 3rd NC, as associated with differences in the spatial resolution of the analysis; finer in the FREL calculation than in the GHGI estimates. However, there are large differences in the total amount of GHG emissions reported in the FREL (+40%) compared to the GHGI and the opposite trend, decreasing in the FREL (-64% from 2001 to 2010) while stable (or even slightly increasing) in the GHGI.

Brazil's Nationally Determined Contribution

The Brazilian NDC established a single economy-wide GHG reference level, i.e. the 2005 GHG net emissions[56]. Against this baseline, Brazil committed to reduce its net emissions 37% by 2025, and 43% by 2030. Brazil is one of the few developing countries that has chosen a base year rather than a projected BAU scenario as its baseline; it may be advantageous to do so due to the high level of deforestation (and therefore emissions) in 2005.

To achieve this goal, Brazil intends to adopt measures that suggest a large contribution from the land sector and in particular from forest land, including:

i. increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030, which may include the expansion of sugar cane plantations;
ii. strengthening and enforcing the implementation of the Forest Code, at federal, state and municipal levels;
iii. strengthening policies and measures with a view to achieve, in the Brazilian Amazonia, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030
iv. restoring and reforesting 12 Mha of forests by 2030, for multiple purposes;

[56] NDC includes GHG emissions from deforestation as well as GHG emissions and removals from forest land

v. enhancing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices;
vi. in the agriculture sector, strengthen the Low Carbon Emission Agriculture Program (ABC) as the main strategy for sustainable agriculture development, including by restoring an additional 15 Mha of degraded pasturelands by 2030 and enhancing 5 Mha of integrated cropland-livestock-forestry systems (ICLFS) by 2030.

Finally, it should be noted that because the NDC baseline is the 2005 level of GHG net emissions (i.e. a 'base year' approach), accounted reductions in emissions from deforestation may largely differ from those accounted for using the FREL. This will, of course, affect the fungibility of emissions reduction units accounted for under any trading mechanism that includes REDD+ with the Paris agreement contributions—that said, Brazil's policy to date has been to not allow the trading of forest offsets.

Sources

Brienen et al, Long-term decline of the Amazon carbon sink. Nature 519, 344–348 (19 March 2015) doi:10.1038/nature14283

Rajao et al (2017). Correspondence to Conservation Letters: The Rights and Wrongs of Brazil's Forest Monitoring Systems

In addition to the GHGI and REDD-plus reports, other Brazilian data sources on the land sector are also available (see Annex II).

Canada

As of 2010, Canada was ranked as the 9th largest GHG emitter in the world. With the incremental accumulation of C stocks in the HWP pool, Canadian managed forest land (226 Mha) has been a net sink of GHG since the year 2000. However, if it is assumed that harvested carbon is instantly oxidized and the C accumulation in HWP is not included, then the forests appear as a net source in every year since 2000 except for 2001 and 2009. Canadian forests have been subject to a continuous degradation process since 2000 (see Annex IIb, Table 1), caused by the combined impact of human activities (harvesting, man-made fires[57], deforestation) and changes in climate that have increased the frequency and severity of disturbances (fire, pest).

According to FRA 2015, Canada has the third largest forest area in the world (or 8.7% of the global forest area). Forests cover 34.7% of the total national territory, and are continuously decreasing from 348.3 million hectares (34.9%) in 1990, to 347.8 Mha (34.8%) in 2000, to 347.1 Mha in 2015. Average annual deforestation in Canada in the last 15 years is less than 50,000 hectares or less than 0.015% per year. Canada also contains a very large area of peat (110 Mha)[58].

The latest GHGI of Canada was submitted to the UNFCCC in April 2017 and is the basis of this analysis. It covers all C pools of all forest-related GHGI categories (NF→F, F→F, F→NF) and separates out managed forest land (226 Mha), where GHG emissions and removals are estimated, from unmanaged forest land (121 Mha) where GHG emissions and removals are considered to be caused predominantly by natural factors and therefore not estimated[59]. Estimates are made applying country-specific methods and mapping for activity data.

This analysis compares the national GHGI estimates with two alternative estimates, FRA and Houghton, and found little to no agreement among any of the three estimates. The main differences are due to the exclusion of net emissions from "natural disturbances"[60] in the GHGI and CO_2 removals in Houghton estimates, since those are both considered non-anthropogenic. Nevertheless, all three estimates show an increase of net emissions across the time series 1990-2015. For the GHGI this is mainly consequence of a large-scale outbreak of the Mountain-Pine Beetle, and associated salvage logging, which affected some 18 Mha of forest areas in western Canada.

Canada's reporting under the UNFCCC

Canada submits annual National Inventory Reports and, in addition to these, has submitted 6 National Communications and 2 Biennial Reports. The latest complete GHGI of Canada has been submitted on April 13, 2017. The country reported to the Kyoto Protocol for the 1st commitment period only until its withdrawal from the Protocol in 2011. The country submitted its first NDC on May 11, 2017. It is an economy-wide contribution that includes the land use sector.

[57] Causes of man-made fires in forests include accidental and intentional causes as: Burning Debris, Unattended Campfires, Equipment Failure or Engine Sparks, Cigarettes and Lighters, Fireworks, Arson. According to Natural Resources Canada, humans cause slightly more than half of all wildland fires in Canada, although these are usually spotted early and can be reached quickly by firefighting crews (http://www.nrcan.gc.ca/forests/fire-insects-disturbances/fire/13145).

[58] http://w ww.peatsociety.org/peatlands-and-peat/global-peat-resources-country

[59] Although any emission and subsequent removal from deforestation events in previously unmanaged forest land is reported, since when deforestation occurs the land is reclassified as managed.

[60] According to the Canadian GHGI, "natural disturbances" include wildfires, insect infestations and wind throw. Emissions and removals from stands dominated by the impacts of these disturbances are temporarily excluded from GHGI reporting. Stands are considered to be dominated by natural disturbances when subject to stand-replacing wildfire or wind throw, or subject to insect infestations that causes more than 20% biomass mortality,

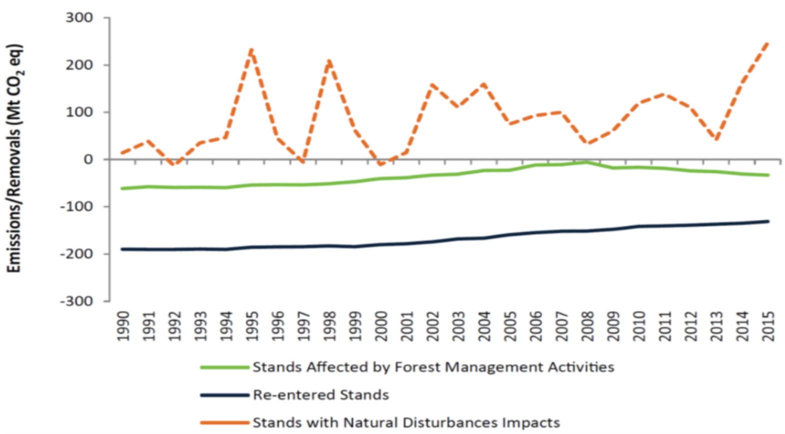
What forest fluxes are included in the GHGI?

Canada's reporting on the LULUCF sector in its GHGI is prepared applying the 2006 IPCC Guidelines in conjunction with the 2013 IPCC Wetlands Supplement. Consequently, Canada applies the managed[61] land proxy. This means that the GHGI does not include GHG emissions and removals from forest land classified as unmanaged forest, although any conversion of unmanaged forest (i.e. F→NF) caused by human activities is reported.

In its most recent GHGI, Canada excludes from its GHGI estimates of emissions (and subsequent removals) from stands dominated by "natural disturbances" (defined as stand-replacing wildfires and wind throw, and insect infestations that cause biomass mortality of greater than 20%). It does so by excluding[62] from its reporting the land[63] where those disturbances occur. Subsequently, disturbed land where the tree cover was completely lost (i.e. stand-replacing disturbances) is re-included into the GHGI estimates 60 years after the disturbance's occurrence, while partially disturbed land that had greater than 20% biomass mortality is reintroduced into the GHGI as soon as the biomass stock achieves the pre-disturbance level. However, the NIR does not contain a reporting table with annual estimates of GHG emissions and CO_2 removals excluded from the GHGI estimates. The NIR does not provide information on how areas affected by stand-replacing fires, dating back to1931, have been identified by distinguishing them from harvested areas; although it seems that forest inventories collect information on the latest stand-replacing disturbance where available. Therefore, the analysis of the impact of such exclusion is based only on information reported in a NIR Figure (see Figure below).

Emissions and Removals in Forest Land Remaining Forest Land by Stand Component

Source: Canada's 2017 GHGI (NIR, Figure 6.3)



The Figure above shows that there is an increasing trend in the emissions impact of "natural disturbances"[60] (i.e. dotted red line) that the methodology applied omits from reporting. According to Canada[64]: "The black line represents all areas affected by stand-replacing disturbances 60 or more years ago, in practice, it is the total area of managed forests in Canada that are 60 years or older and have never been harvested. The green line represents all lands that have been harvested at any time in the

[61] For the GHG inventory, managed forests are those managed for timber and nontimber resources (including parks) or subject to fire protection
[62] Boreal forests are naturally affected by stand-replacing disturbances (e.g. wildfires) so that the threshold selected does not allow to separate out extreme events from a natural background level of disturbances. Such separation is for instance required by the IPCC default methodology contained in Supplementary Guidance for the Kyoto Protocol).
[63] On average, 40 Mha has been excluded across the time series (NIR table 6-5).
[64] Personal communications with Natural Resources Canada.

past. As harvesting continues in Canada land will be transferred from the category shown by the black line to land included in the green line. Natural disturbances also affect lands shown by the black line – so some of the decrease in the sink in the black line is because lands are disturbed by fires and transferred to the redline." The figure shows that the stands that were impacted by disturbances and that re-enter the reporting after the 60 years set aside (in the case of stand-replacing disturbances), or once biomass returns to the pre-disturbance level (in the case of the stands dominated by insect infestation, i.e. greater than 20% biomass mortality), are the predominant sink in forest land although the sink is decreasing.

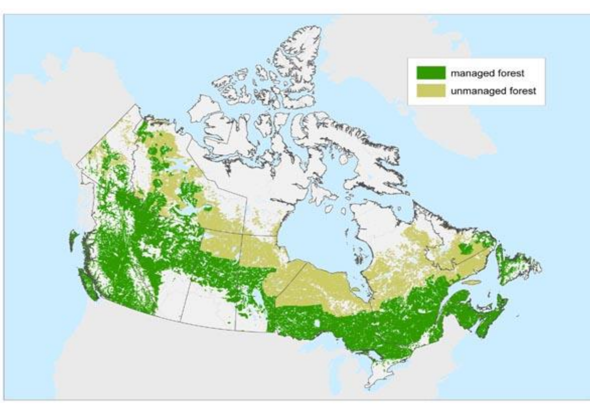
Because the methodology applied excludes all stands that are dominated by disturbances (as explained above), it means that also some direct human-induced emissions and subsequent removals (e.g. from man-made fires[65]) and indirect human-induced GHG fluxes (e.g. exacerbation of fire and pest occurrences caused by climate change[66]) are excluded from the GHGI. Further, because the 60-year rule does not ensure that subsequent removals excluded from reporting are equivalent to the emissions excluded, and because salvage logging of disturbed land means some lands re-enter into reporting before the 60-year period has expired, there is an imbalance between emissions and removals excluded; such asymmetry increases across the time series since the impact of disturbances is increasing.

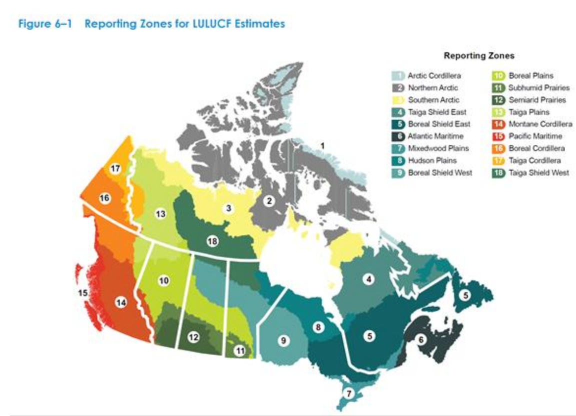
Canada is working on revising the 60-year re-entry threshold to a range of regionally-differentiated values based on forest management criteria. This revision will likely lead to older re-entry ages, and thus reduction of removals currently reported in the GHGI. Further, if the disturbed land is subject to forest management activities—including commercial clearcut and partial harvest, commercial and pre-commercial thinning, and salvage logging—then it is immediately re-entered into the reporting, even though re-entry criteria (see above) have not been met. This means that emissions associated with these activities will be included in the reporting as will the removals associated with the existing forest or that occur subsequent to the management activity.

Across the time period 2010-2015,[67] Canada estimates that net emissions from disturbances totaled 820[68] $MtCO_2$. Therefore, on average the atmosphere has seen around 140 $MtCO_2$ yr^{-1} of annual net emissions[69] from managed forest land in Canada.

Unmanaged and managed forest in Canada's GHGI (left) – Reporting Zones for GHGI (right)

Source: Canada's 2017 NIR





[65] This does not include prescribed burning

[66] http://www.nrcan.gc.ca/forests/fire-insects-disturbances/pest-management/13389

[67] See NIR table 6-5

[68] 14 $MtCO_2$ in 1990, 75 in 1995, 120 in 2010, 140 in 2011, 110 in 2012, 41 in 2013, 160 in 2014, 250 in 2015.

[69] Values reported in Table 1, Annex II, plus emissions from disturbances reported in NIR table 6-5

The Canadian forest definition applied in the GHGI has the following thresholds: minimum size 1 ha, minimum height 5 m, minimum crown cover 25%. The GHGI includes time series of annual GHG estimates, for the period 1990-2015, for all forest-related land categories: NF→F, F→F, F→NF (GHGI's Tables 4.1, 4.A, 4.B, 4.E and 4(V); disaggregated by reporting zones).

Deforestation is estimated by an operational monitoring system[70] based on samples extracted from remotely sensed Landsat images dated circa 1975, 1990, 2000, 2008 and 2013; and cross-checking that information with databases, air photos, ground checks or other documentation on forest roads, power lines, oil and gas infrastructure, and hydroelectric reservoirs. Afforestation is estimated through administrative records.

Estimates of C stock changes and associated emissions and removals are prepared by using the country-specific Tier 3 model CBM-CFS3 (Kurz et al, 2009; Stinson et al, 2011). The model prepares GHG estimates of all gases for all C pools for the three forest-related categories (NF→F, F→F, F→NF). Growth is simulated as an annual process using yield curves of merchantable volume over time. Thereafter, the C accumulated by growth follows several transfers to other pools and of decay to the atmosphere per natural processes (e.g. mortality, mineralization of C stocks, disturbances) and human activities (e.g. harvesting) all simulated by the model that calculates GHG emissions and removals associated with such processes[71].

Input data come from the forest management and inventory databases of Provinces and Territories. Areas disturbed by wildfires are extracted from the Canadian Wildland Fire Information System's National Burn Area Composite (NBAC); a composite of low- and medium-resolution remote sensing data and fire mapping data prepared by the Canadian Forest Service and combined with data provided by resource management agencies from across Canada. Insect disturbances are monitored by aerial surveys, which record the area impacted by the disturbance and assign an impact severity class that indicates the degree of tree mortality or defoliation.

The GHG inventory reports C stock gain and losses and associated GHG emissions and removals for all C pools and gases of all forest-related GHGI categories (NF→F, F→F, F→NF), and therefore may be considered complete.

Forest-related category coverage in Canadian submissions to UNFCCC

	F > NF	F > F	NF > F
GHGI (2017)	Estimates land-use conversion from forest through operational deforestation monitoring program. C stock changes and associated GHG fluxes are estimated through the CBM-CFS3 model	Estimates the forest area through the National Forest Inventory framework. C stock changes and associated GHG fluxes are estimated through the CBM-CFS3 model	Estimates land-use conversion to forest through administrative records only. C stock changes and associated GHG fluxes are estimated through the CBM-CFS3 model

Other GHG fluxes that are not estimated, both due to model constraints and because Canada considers such impacts not anthropogenic[72], include:

[70] https://cfs.nrcan.gc.ca/publications?id=36042
[71] A second model tracks the fate of the carbon transferred from forests to the HWP sector – this is not done within the CBM-CFS3
[72] Personal communications with Natural Resources Canada

- Incremental fluxes from environmental impacts, such as CO_2 fertilization, N deposition or temperature and precipitation changes (Kurz et al, 2013);
- Impact of harvesting on organic soils.

The impacts on unmanaged lands are considered non-anthropogenic (and therefore not required reporting under the UNFCCC). Unmanaged forest land in Canada covers almost one-third of the entire forest area[73]. The GHG balance of these forests is unknown (Kurz et al, 2013), although emissions and removals may be affected by:

- increase in frequency and intensity of wildfires;
- CO_2 atmospheric increase;
- increase in temperatures that affect growing season and the permafrost layer;
- deficits in the evapotranspiration balance;
- N deposition.

Also, because of the large presence of peat soils, net GHG fluxes from unmanaged forests could significantly change the quantification of the actual contribution of forest land in the land-atmosphere GHG balance of the country. While indirect human-induced impacts may occur on unmanaged lands, they are assumed likely less relevant than natural drivers of emissions and removals.

Uncertainties

In Canada's NIR, uncertainties[74] of GHG estimates have been estimated by applying Monte Carlo analysis. For F→F: uncertainty of CO2 net removals is -34% +6%, for CH_4 emissions is -30% +119% and for N_2O is -30% +129%. Uncertainties of NF→F and F→NF are larger because higher uncertainty in activity data; uncertainties of net removals in NF→F are reported as estimated by expert judgement as -200% +10%, while uncertainties of F→NF are estimated by IPCC Tier 1 method as ±34%. (see also Metsaranta et al, 2017)[75]

Comparison of national reporting to independent studies

This section provides a comparison of several estimates of Canada's forest fluxes. The varying estimates illustrate the issues raised in the main report[76], i.e. that estimates of forest fluxes can differ due to interpretations of "what is anthropogenic", differences in what is being measured, and varying methods used. As with all the case studies in this working paper, several hypotheses are put forward to explain potential reasons for apparent discrepancies, although further work is required to fully understand (and therefore fully reconcile) the estimates.

The following table summarizes the total GHG net emissions/removals from the three forest-related categories (F→F, NF→F, F→NF), as reported by Canada in its 2017 GHGI[77], those calculated from data submitted by Canada to FAO's FRA[78], and those estimated by Houghton's bookkeeping model[79].

[73] All of this area is in the North of Canada – the two huge territories in Canada's North have an area of over 180 Mha and a population of about 85,000 people – most in the two capital towns. Thus human activities are negligible and limited to those portion of forest reported as managed
[74] http://www.nrcresearchpress.com/doi/abs/10.1139/cjfr-2017-0088
[75] Uncertainty of inventory-based estimates of the carbon dynamics of Canada's managed forest (1990–2014)
[76] GHG Fluxes from Forests: An assessment of national GHG estimates and independent research in the context of the Paris Agreement.
[77] Canada's 2017 NIR (available at http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions)
[78] Federici et al (2015), available at http://www.sciencedirect.com/science/article/pii/S0378112715002443.
[79] Houghton and Nassikas (2017), unpublished.

Comparison of GHG fluxes from forests by category (2011-2015 average)

Source	F→F	NF→F	F→NF	Total	C pool	GHG
	Mt CO_2eq yr^{-1}					
GHGI[80] - 2017	-22.7	-0.6	7.5	-15.8	AGB, BGB, DOM, SOM[81], HWP	CO_2, CH_4, N_2O
FAO FRA[82] 2015	38.7	-141.9*	160.2*	57.0	AGB, BGB, DOM, SOM[83]	CO_2,
Houghton - 2017	59.9	38.4* ‡	87.7*	185.9	AGB, BGB, DOM, SOM[15], HWP	CO_2

* net forest area changes; derived using net change in planted forest (for NF→F) or natural forest (for F→NF)
‡ forest plantations only

While the GHGI reports a net sink from managed forest land, even though non-CO_2 emissions have been included, derived estimates from FAO FRA data and Houghton estimate a net source. Differences may be partially explained by the following:

- Estimates in the FRA for C stock densities are underestimated since FRA calculates them from total C stock estimates reported by Canada for managed land divided by the total forest area (which includes also 180 Mha of unmanged forests. However, this does not impact the total forest C stock change calculated as the sum of the three forest-related categories;
- FRA does not include the HWP sink (it then implicitly accounts any HWP as instantaneously oxidized), where some of the transferred carbon from forest are stored for long periods and therefore the data overstates net emissions;
- Assumptions about instantaneous changes in AGB, BGB, DOM and soil C stock for F→NF and NF→F for the FRA calculations, which actually occur over time (and may change the annual estimates);
- Houghton excludes most of the forest sink (i.e. growth increments in non-harvest areas), since considered natural, although it includes the HWP sink. It also excludes all emissions and subsequent removals from disturbances.
- The GHGI and FRA use different definitions of land subject to F→NF and NF→F. GHGI follows definitions consistent with IPCC (i.e. creation or loss of forest, respectively, associated with a change in land use). FAO uses the decrease in land classified as natural forest for F→NF and the increase in land classified as planted forest for NF→F, and this captures substantial movement of land from the categories of natural forest to planted forest as well as deforestation and afforestation in the IPCC sense.

Given the above differences, the cumulative estimates of total net CO_2 emission from forest land also differ significantly among the three estimates (see Table below). While the GHGI reports a cumulative net sink from 1990 to 2015, both FRA and Houghton's estimates suggest that Canadian forests are a net source of emissions to the atmosphere.

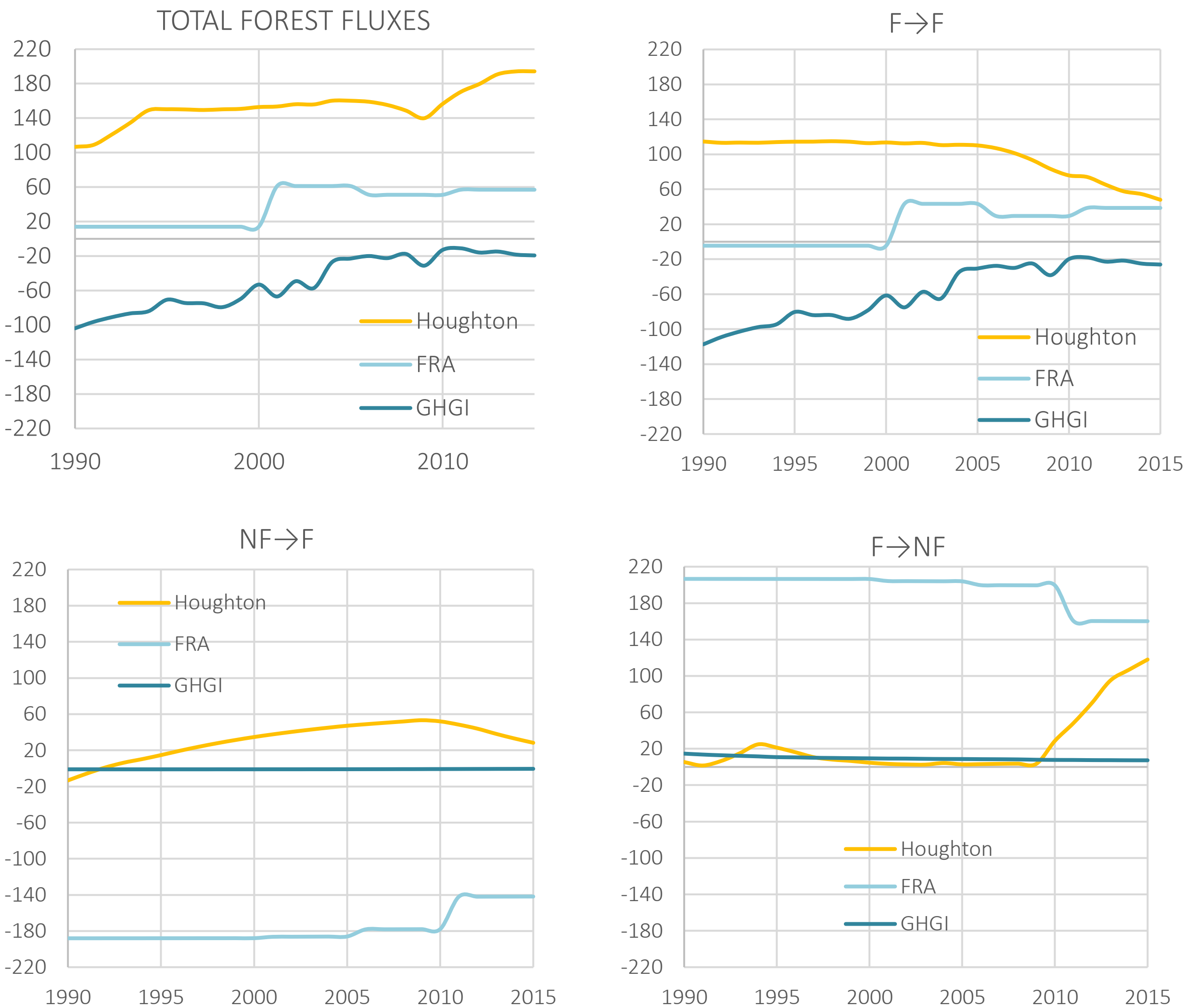
[80] Values in parenthesis have been estimated by allocating HWP biomass losses due to roundwood export.
[81] Mineral soils only.
[82] See Annex for information on how estimates were derived from FAO FRA data.
[83] http://www.fao.org/3/a-az181e.pdf

A comparison of cumulative total net emissions from forest land, 1990-2015

Cumulated net emission from forest land (including deforestation)	GHGI	FAO FRA[84]	Houghton
	Mt CO_2eq		
1990-2015	-1,290	1,001	3,999

Below is a comparison of time series of GHG fluxes for each forest-related category and for the totals, as reported by GHGI, FRA and Houghton. Regarding total net emission from forest, all estimates show a similar trend of increasing emissions across the 1990-2015 time series. However, trends for each of the three forest-related GHG categories differ among the estimates.

Comparison of GHG fluxes by forest-related categories (Mt CO_2eq)



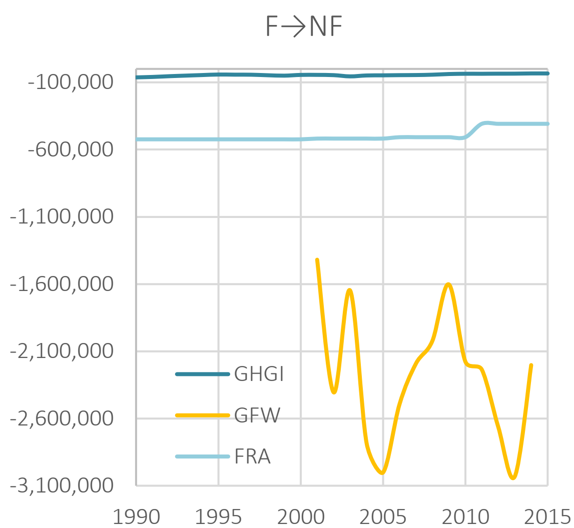
Estimates of GHG emissions/removals for any single category are not comparable due to differences in definitions and methods. However, at level of total forest fluxes the difference between the GHGI and

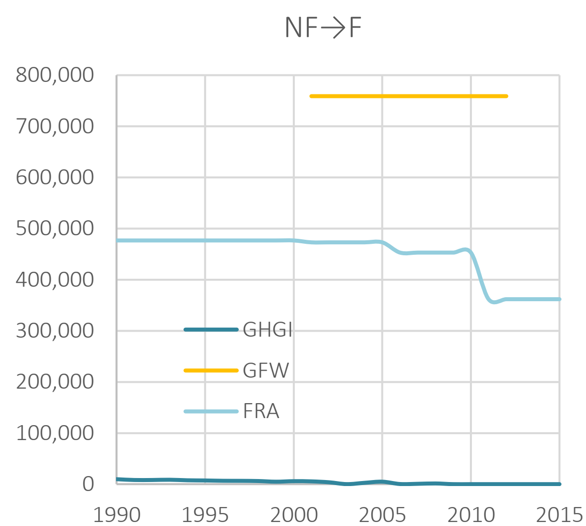
[84] A comparison for the cumulative C stock change (net emission from forest land including deforestation) for the period 1990-2010 is reported as 1,074 MtCO_2eq (FAO FRA) and -588 MtCO_2 (GHGI).

derived estimates from the FRA may be largely explained by the fact that FRA does not account for storage of carbon in harvested wood products, the use of a new version of the Canadian model in the GHGI compared to that used to provide data to FRA, and to the exclusion of emissions and removals from disturbances in the GHGI estimates as noted previously.

Differences between estimates in the GHGI compared to Houghton cannot be explained by a different treatment of GHG fluxes from disturbances since also Houghton excludes them. Further, both estimates use the same source of data to calculate biomass C stock losses associated with harvesting. However, while the national GHGI reports a net sink in biomass because HWP accumulation and also a net sink in SOM because increased amount of C inputs caused by disturbances (including salvage logging), Houghton reports a net loss in both the biomass, including HWP and SOM pools. Differences are therefore in the net increment rate of biomass applied, in the area of managed forest across which such increment is applied, and in the assumption in Houghton's model of SOM at equilibrium in forest land remaining forest land.

Below is a comparison of time series of annual areas (ha yr^{-1}) for the forest-related categories: NF→F and F→NF, as reported by GHGI, FRA and GFW. The comparison again illustrates points made in the main report on why there are differences in forest flux estimates across sources of information—in this case, much of the apparent discrepancy may be attributed to definitional differences (as discussed below).



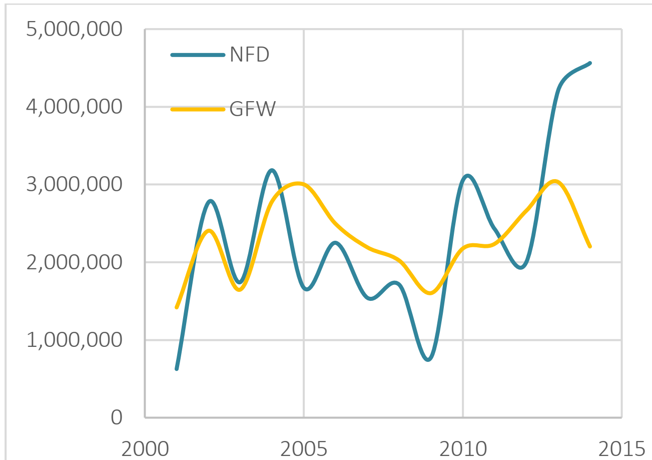


- ✓ For F→NF:
  - GHGI reports gross deforestation;
  - FRA reports net losses in the area of natural (including secondary) forest
  - GFW reports gross tree cover loss
- ✓ For NF→F:
  - GHGI reports gross afforestation;
  - FRA reports net increases in the area of planted forest
  - GFW reports gross tree cover gain

Large differences with GFW may be explained by stand-replacing disturbances, including harvesting, that are reported within GFW as tree cover loss data (which usually is temporary, e.g. forest regenerates after harvest or fire), while they are excluded from FRA and GHGI data so far as the land use does not change. So, it is expected that GFW would have both larger (gross tree cover) loss and gain estimates compared to changes in land use from the GHGI or FRA data.

Differences between the GHGI and FRA are due to the use of different definitions of forest conversion. The FRA estimates are based on equivalent changes, i.e. a large net decrease in 'natural forest[85]' and an almost equivalent large net increase in 'planted forest'. Those two processes are likely the result of a substitution of natural forests with planted forests, so that definitions of deforestation and afforestation applied in the FRA analysis differ from those based on UNFCCC and IPCC definitions used in GHGIs. This substitution effect, i.e. planted forests on natural forests, may help to reconcile (at least partially) the FRA and GHGI estimates. Although across the time series 1990-2015 FRA reports a net forest loss 15% higher than that reported in the GHGI.

The chart to the right compares GFW tree cover loss with area burned as reported by Canada's National Forestry Database (2017). While area burned is not the same as tree cover loss, the chart seems to confirm that fire is the major cause of forest cover loss and that Canada's data on emissions from fire could be validated by an independent source of data. However, forest fires emissions are not currently included in the GHGI estimates of anthropogenic emissions and removals (as discussed above).



Canada's Nationally Determined Contribution

The Canadian NDC established a single economy-wide GHG reference level and uses a base year approach, i.e. 2005 GHG net emissions for the baseline from which Canada has committed to reduce unconditionally its emissions 30% by 2030. Further, Canada is taking action to reduce black carbon, a short-lived climate pollutant of particular significance in the Arctic due to its contribution to Arctic warming. Forest fires are a significant source of black carbon: Canada's actions prevent and fight fires and to reduce their frequency and intensity in order to protect lives, communities and the natural resources will also reduce black carbon; although since fire is a necessary ecological process of regeneration for boreal forests, they cannot be completely avoided.

The NDC includes a limited contribution from the land use sector, with forest land included in a mix of undefined mitigation measures such as investment in public transport, technology innovation, and green infrastructure: together these are expected to contribute 44 Mt of CO_2eq to the overall target.

Finally, according to the NDC, Canada is examining its approach to land use accounting. It states that it will apply a "production approach" to account for HWP and exclude the impacts of natural disturbances and focus on direct human-induced[86] emissions and removals, as defined by the country.

[85] FRA categories: "Primary forest" and "other naturally regenerating forest"

[86] GHG emissions and removals in the land use sector are caused by the concurrent impacts of direct human-induced causes (e.g. harvesting, fires), that are under the exclusive control of the country, indirect human-induced impacts (CO_2 and N fertilization, climate change), that are the collective responsibility of countries, and natural variability (whose impacts average out across time).

Sources

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China

China is the world's largest GHG emitter with total national emissions of 11,320 $MtCO_2eq$ in 2012. The land-use sector is a significant sink of 576 $MtCO_2eq$, but amounts to only about 4% of the national GHGI. Land-use related fluxes are dominated by forest land remaining forest land, where increments far exceed harvests.[87]

China also has the world's largest plantation area, at 69 Mha in 2012, according to the BUR. An immense land restoration and forest planting effort is being undertaken in the context of the Three North Shelterbelt project (Li et al., 2012) that since 1978 has sought to create a 'Green Wall' against the Gobi desert's advance. By its completion in 2050, the Green Wall should stretch 4,500 km along the edges of China's northern deserts, covering more than 400 Mha. The national forest inventory (NFI) reports that from 1990-2010 forest areas increased by an average of 3.7 Mha every year. There is, however, some disagreement about the success of such plantings (e.g. Cao et al., 2011) and thus about the quality of official data that show a successful restoration effort at unprecedented scale.

Most of the available data on China's forests, forest change trends and their GHG emissions are derived from repeated NFIs. The inventories are the direct or indirect basis for most reporting and quantification efforts, including China's country reports to FAO's FRA, GHGIs reported to the UNFCCC, as well as independent efforts to estimate forest GHG fluxes. Despite this fact (i.e. that nearly all studies are based on a common source), emission and removal estimates vary among sources. Some of the differences relate to definitions and coverage. A lack of transparency in the national GHGI inhibits an ability to fully reconcile datasets.

China's reporting under the UNFCCC

China has submitted two national communications and one BUR to the UNFCCC. These contain GHGIs for the years 1994, 2005, and 2012, respectively. All GHGIs reported to the UNFCCC were developed largely using the revised 1996 IPCC Guidelines[88]. Although formally these are still the only required guidance for developing country GHGIs, countries should use the 2003 Good Practice Guidance (GPG) for BURs. Many developing countries (even those smaller and less resourced) have begun routinely using the updated guidance for their GHGIs, suggesting that China does not seem to have drawn on all available capacities. Coverage of land use-related fluxes is limited, with only two of the five top-level GHG categories included for the sector. The level of detail provided when describing methodologies and results is at odds with an expectation of high technical capacity in China.

On the other hand, efforts to report forest-related GHG emissions and removals are firmly grounded in China's national forest statistics based on its NFI. China counts among few countries that have regularly conducted NFIs since as early as the 1970s. The structure of information provided in available GHGIs is virtually identical. The reporting effort is part of a larger statistical system (and not collected ad hoc). Such government ownership and sustainability of data collection efforts are uncommon among developing countries and are key factors for guaranteeing continuous, high-quality GHG estimates.

[87] Figures in this paragraph from China's BUR.
[88] In several places, the 2003 GPG and 2006 IPCC Guidelines were referenced; however, the reporting is largely based on the 1996 IPCC Guidelines.

What forest fluxes are included in the GHGI?

Forest definition: China defines forests to include a range of vegetation types. Arboreal forests have tree species above 20% crown cover, with an area of 667 m^2, a height at maturity of 2 m or greater, and a minimum width of 10 m. The GHGI also includes bamboo forests, and forest belts either with over two rows and less than 4 m of inter-row distance or a canopy width of more than 10 m. The forest definition has changed several times, including in the 5th NFI (1994-1998), when the crown cover threshold was decreased from 30% to 20%. And indeed, China's Initial National Communication (1994) contains an estimated total forest area of 129 Mha, compared with 159 Mha reported in the 5th NFI. With changing definitions, the GHGI from 1994 may not be strictly comparable to the GHGIs reported in 2005 and 2012.

There is no indication that China uses the managed land proxy (which was not introduced until the 2003 GPG). China's 2015 country report to FAO's FRA indicates that about 10% of the country's forests are still considered primary forest. While some other countries have excluded such primary vegetation from their national GHGIs, all of China's forests may be considered to be under some sort of management (e.g. forest protection).

Activity coverage: The GHGI covers only two of the top-level source categories in the 1996 IPCC Guidelines: changes in forest and other woody biomass stocks and forest and grassland conversion. Among other things, it does not report on the abandonment of managed lands and emissions and removals from soils. Abandonment of managed lands occurs in slash-and-burn agriculture, which is a phenomenon more prominent in other countries than in China. Emissions and removals from soils chiefly occur in conversion between forest land and croplands or grasslands. Houghton estimates 16.5% of forest-related GHG emissions and removals are from soil-carbon stock changes, which the GHGI omits.

For estimating emissions and removals in forest land remaining forest land (i.e. changes in forest and other woody biomass stocks), a combination of gain-loss methods and stock-change methods are used, depending on the forest type. The increments from forest growth and harvesting are estimated using a gain-loss method. There is no reference made to disturbances. At least with regards to fires, this omission may only introduce limited underestimation (see below).

	Forest-related category coverage		
	F > NF	F > F	NF > F
First BUR (2012 GHGI)	• Forest and grassland conversion	• Changes in forest and other woody biomass stocks	• Changes in forest and other woody biomass stocks

Pools: The GHGI is largely based on the NFI that includes estimates of the growing stock in above-ground biomass of living trees above a certain diameter threshold. The GHGI uses expansion factors to arrive at the full volume. There is no conclusive information in either the BUR or the NCs on whether below-ground biomass and dead wood were also included, but information in the reports to FAO's FRA indicates that the relevant information is available. Soil-organic carbon, however, seems to be excluded (see above).

Non-CO_2 gases: The GHGI includes CH_4 and N_2O emissions from the burning of biomass during forest and grassland conversion. These make only a minor contribution to aggregate emissions, and are less than 0.1% of forest sector fluxes. The GHGI does not, however, include non-CO_2 gases for fire events that occur in forest land remaining forest land, at least not explicitly. However, this is unlikely to have a major impact on total flux estimates. FAOSTAT estimates less than 2 $MtCO_2eq$ per year from biomass burning.

Uncertainties

The BUR reports an uncertainty level of 43.25% for the total land-use removals without providing detail on the estimation. Generally speaking, the reported uncertainty level is plausible. The Initial and Second NCs include only a qualitative discussion of key sources of uncertainty, for example, discussing errors from the use of default factors and stock measurements.

Comparison of national reporting to independent studies

Differences between aggregate forest-related fluxes estimated in the GHGI compared to other data sources, notably Houghton and FAOSTAT are significant (see Table below). This is perhaps a surprising result because China's NFI is the most important source of information for the GHGI, for China's country report to the FRA (where it becomes basis for data in FAOSTAT), and for Houghton's estimates that largely draw on FRA country reports.

Aggregate estimates for GHGI categories

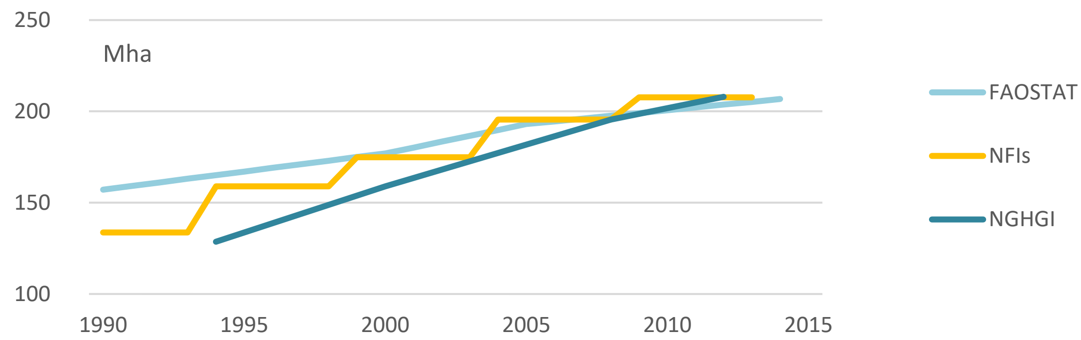
Averages of the years 1994, 2005 and 2012 in tCO_2eq

	F→NF	NF→F	F→F
GHGI (BUR, 2017)	23,635,777	- 491,690,667	
	TOTAL (net removals): **-468,054,890**		
Houghton	- 100,213,997		- 67,306,624
	TOTAL (net removals): **-167,520,621**		
FAOSTAT	0	- 326,137,778	
	TOTAL (net removals): **-326,137,778**		

The following points out how some of the differences may be explained through the coverage of emission sources. Notably, disaggregating Houghton's dataset into emissions from non-forest land converted to forest land, and excluding emissions in non-forest land from the GHGI may account for some of the discrepancies.

Forest area: On China's total forest area, more recent data sources compare well, including the data that underlies the GHGI, which itself is largely based on the NFI (see Figure below). Differences in earlier years may be due to changing definitions (see above), for example the 1994 GHGI used a forest area estimate about 20% lower than the estimate in the 5th NFI (1994-1998). Data in FAOSTAT more closely align with the NFIs because China drew on them for reporting to FAO, although with some adjustments to account for differences in forest definition.

Forest area estimates for China

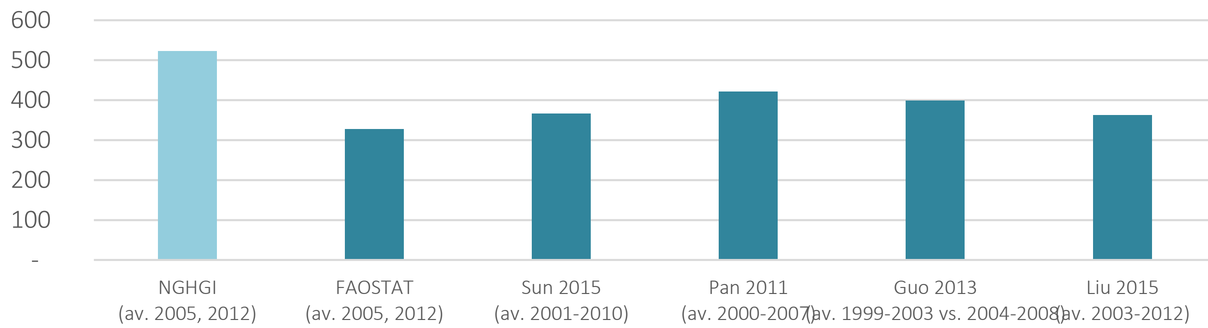


Concerns have been raised on the quality of the forest area statistics. Survival rates in tree plantations from 1952-2005 have been independently estimated as low as 24% (Cao et al, 2011). While China's FRA report suggests that China does not assume all planting results in forest area expansion, official forest area statistics may still overestimate true forest area. The comparison against data from Houghton or the GHGI does not provide clues on this because they all derive from the NFI, but Hansen's dataset independently reports forest area gains (albeit at a much higher crown cover threshold of 50%) that amount to only 7% of the NFI results for the years 2001-2012.

Forest increment: The increment in standing forests is reported as a large sink in the GHGI, for arboreal forests alone estimated at (gross) -756 MtCO$_2$eq in 2005. Information in the FRA 2015 country report implies similar annual increments for arboreal forests of -689 MtCO$_2$eq in the same year. Comparison of net removals in the GHGI against the results of several independent studies using a variety of approaches and data sources shows the GHGI estimates net removals 20-30% higher than other sources (see Figure below). Differences likely derive from forest area or forest growth estimates or their combination, but the GHGI includes scant methodological detail making it hard to understand the origin of observed discrepancies. For arboreal forests, the SNC implies[89] that the increment factor applied is a moderate 1.33 tC per year and ha. Low success rates in plantation establishment (see above) may introduce bias in forest area estimation and contribute to the comparatively high removal estimates in the GHGI.

Biomass removals in China's forests (MtCO$_2$eq/yr in F→F and NF→F)

During the 2000s as estimated by several independent sources and in the GHGI



Sources: Sun et al.,2015; Pan et al, 2011; Guo et al, 2013; Liu et al, 2015.

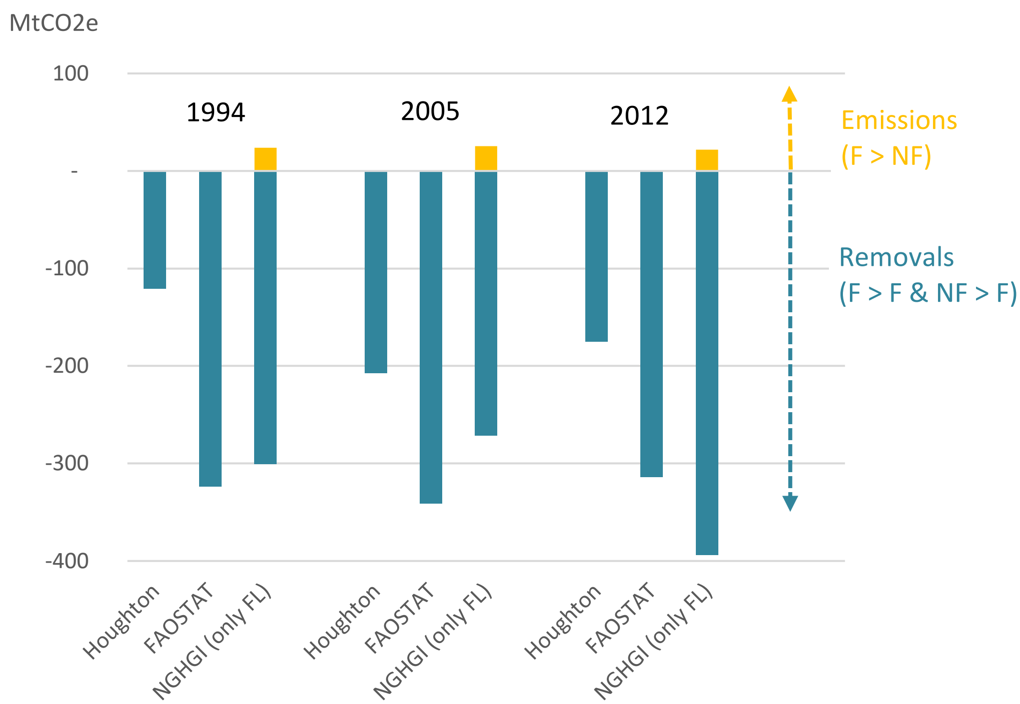
[89] This was derived by comparing the SNC's estimate on aggregate growth of arboreal forests against the estimate of arboreal forest area from the FRA 2015 country report.

Net emissions and removals: Although sizeable differences remain, the Houghton dataset, FAOSTAT data and the GHGI are more comparable if correcting for different coverage (see Figure below). For one, 130-200 $MtCO_2eq$ of removals in shrublands, bamboo forests, and other treed land need to be excluded from the GHGI if comparing against forest data from other sources. Second, natural regeneration needs to be separated from natural forest loss in the Houghton dataset to make both the estimated of forest conversion and of forest loss comparable to other data sources.

After such corrections, for forestland remaining forestland Houghton estimates net removals around 100-200 $MtCO_2eq$, but both FAOSTAT and the GHGI are closer to 250-400 $MtCO_2eq$. These net figures are the sum of several fluxes, including emissions from commercial harvests, fuelwood collection and disturbances, and removals from natural forest regeneration, plantation growth and regrowth in natural forests. The GHGI is not sufficiently transparent to explore the origin of different estimates.

Comparison between three sources of emission and removal estimates

In this comparison, the GHGI was corrected to exclude removals from shrublands, while Houghton estimates are disaggregated between forest regeneration and natural forest loss.



China's Nationally Determined Contribution

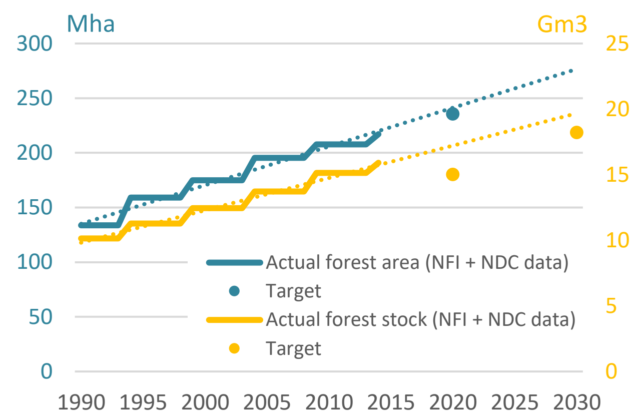
China's NDC renews a 2009 pledge that contains several economy-wide and sectoral targets. For the forest sector, there are no GHG targets provided. Instead, China's mitigation contribution is to increase forested area by 40 Mha and forest stock volume by 1.3 billion m^3 in 2020, compared to the 2005 levels, and by 2030 to increase forest stock volume by around 4.5 billion m^3 above the 2005 level. The NDC uses 2014 data that are not yet included in the BUR to point out that the 2020 forest volume target is already achieved and the forest area target in reach.

By their formulation, the forest-related targets will not be monitored by the GHGI. However, the BUR and the NCs routinely include reference to forest volume and forest area statistics, taken from the NFI that may become the basis for evaluating progress against targets. In addition, land use contributes to the country's aggregate GHG emissions and removals and the NDC discusses a broad range of mitigation and adaptation activities. Some of these activities may contribute to increasing forest area and forest volume: further tree planting, the protection of natural forests, forest and grassland restoration, combatting desertification including through shelterbelt, strengthened forest tending and management, preventing forest disasters and reducing deforestation. There is also reference to the use of forest residues for bioenergy generation, to the restoration and improved management of grasslands and wetlands, and to enhancing agricultural production for enhanced soil organic carbon storage.

Trends in emissions and removals

By its past and current trends, China seems well on track to meet its NDC targets for the forest sector. The NDC's forest volume target for 2020 is already achieved. Extrapolating past trends would suggest that the 2030 forest volume target is also within reach, assuming continued growth of existing forests and forest area expansion. The 2020 forest area target will be achieved if past rates of tree planting can be maintained

Figure: China's forest-related targets in the NDC and historical trends.



Sources

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Democratic Republic of the Congo

The DRC's forests cover over half of the Congo Basin's forests and represent 20% of the world's remaining primary tropical forest[90]. The latest national GHGI, included in the Third National Communication (TNC), estimated 156 Mha of tropical forests in 2010 with an annual deforestation rate of around 0.2%. Despite the low deforestation rate, the land-use sector was responsible for more than 90% of the country's total GHG emissions, amounting to 36.5 $MtCO_2eq$ in 2010. The DRC has long been considered a high forest cover-low deforestation country, but deforestation rates have sharply increased. The Department of Forest Inventory and Planning's (DIAF[91]) most recent official data from 2016 show a 0.52% annual deforestation rate in 2010-2014, up from 0.37% annually in 2000-2010 and 0.17% annually in 1990-2000.

The DRC's official reporting on forest area and its changes has long been based on independent information sources. In addition to data made available by OSFAC (not dated), an NGO[92], researchers at the University of Maryland have published forest statistics for the DRC, notably Hansen's tree cover statistics and the work by Tyukavina et al. (2013). DIAF has recently begun collecting their own official forest cover statistics with the TerraCongo programme (DIAF, 2015, 2016). There is only scant availability of information on forest structure from field measurements, although some field data were recently collected with support from JICA and the UN-REDD programme (DIAF, 2017). Moreover, a national LIDAR campaign has been conducted with support by the WWF to generate a forest carbon map (WWF, 2017). The global datasets by Saatchi et al (2011) and Baccini et al (2012) provide independent information on forest biomass.

Technical capacities for GHG estimation are limited in the DRC. The GHGI has potential for improvement in terms of the application of IPCC standard methodologies and the transparency of presentation. The applied approaches and coverage of emission and removal estimates are not always easily understood.

The DRC's reporting under the UNFCCC

The DRC has submitted three National Communications to the UNFCCC. The most recent was submitted in 2015 and included a GHGI for the period 2000-2010. The DRC has not yet submitted a BUR or a REDD+ reference level, but is currently working on the latter with submission planned for early 2018. So far, national GHGIs have been compiled applying the 1996 IPCC Guidelines; the DRC has not applied the latest available guidance, such as the 2003 GPG for LULUCF or the 2006 IPCC Guidelines.

The TNC's GHGI does not include details on the methodological approaches and datasets used to estimate GHG fluxes, dedicating less than three pages of its core text to describe emissions and removals in the forest sector. There is no evidence that it underwent an extensive quality management process.

The DRC is working to develop forest-monitoring capabilities in a REDD+ context with support from the FCPF, the UN-REDD programme, CAFI and other sources. DIAF recently launched a first set of nationally produced forest area statistics. However, collecting field measurements faces enormous difficulties. A recent report (DIAF, 2017) highlighted that it took three years to collect only 50 plot measurements for a pilot national forest inventory. Costs were high because of expensive labor and complex logistics. To circumvent the challenge of accessibility, countrywide LIDAR mapping of forest biomass stocks has been explored as an alternative (WWF, 2017). The forthcoming REDD+ reference level and future GHGIs may therefore draw on much improved data sources and be prepared with more advanced methodologies.

[90] Information directly or derived from data in FAO Forest Resource Assessment (2015)
[91] Direction des Inventaires et Aménagement Forestiers
[92] Observatoire Satellital des Forêts d'Afrique Centrale, http://www.osfac.net/

What forest fluxes are included in the GHGI?

Data sources: DRC's official reporting on forest area and its changes for FAO's FRA, for OFAC-COMIFAC's State of the Forests[93] and for its TNC all used data produced by the FACET[94] project. It is a regional effort, covering several countries in the region, and is led by OSFAC[95], an NGO supported by USAID and the University of Maryland. IPCC default values are the most important data sources for forest biomass density and increment estimates.

Forthcoming GHGI estimates in a BUR or a REDD+ reference level may be able to draw on improved data sources on forest cover and structure. The UN-REDD programme has recently supported the DRC government in building TerraCongo, a government platform to produce official forest cover statistics. Moreover, a fully-fledged national forest inventory will be conducted with support from the Central African Forest Initiative (CAFI) until 2020. Also, WWF has sponsored a national LIDAR mapping campaign.

Forest definition and area: The DRC has a land-cover based forest definition, considering the presence or absence of tree cover as a single key criterion. Estate crops are considered forests, fallows during rotational agriculture (slash and burn) are forests and their clearing deforestation. Neither the datasets included in TerraCongo (DIAF, 2015, 2016) nor data by OSFAC's FACET project, nor the most prominent independent data sources (e.g. Hansen) convert statistics on tree cover loss into deforestation estimates (as a change in land use).

Managed land proxy: The TNC does not distinguish between managed and unmanaged lands, and appears to include all lands in the GHGI (implicitly identifying the entire territory as 'managed'). This leads to surprising results regarding the estimation of removals from forest growth, implied at approximately 270-280 $MtCO_2eq$ per year[96]. Although not explicit, one may infer that the GHGI uses average increment factors of around 0.9-1.0 t d.m. per year and ha[97], applied over the entire forest area. The IPCC guidance recommends using such increment factors for regrowth in managed forests where 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. If, for example, half of DRC's forests were in reality unmanaged then the overestimation would amount to 130-140 $MtCO_2eq$ per year, greatly increasing the country's net emissions from the sector. Further below, it is discussed how stripping out such removals from growth in standing forests helps to reconcile the TNC's GHGI with independent estimates.

Forest-related categories covered: The TNC's GHGI includes both emissions and removals from forest conversion and from forest land remaining forest land. Potential methodological gaps include the use of the managed land proxy, coverage of pools and gases, treatment of illegal harvesting and disturbances, as well as the treatment of peatlands.

Arguably, some emissions from fire are covered in the TNC – as it reports non-CO_2 emissions (see below) that tend to occur during biomass burning. Indeed, fires are relevant for the DRC, particularly along the

[93] l'Observatoire des Forêts d'Afrique centrale de la Commission des Forêts d'Afrique centrale

[94] Forêts d'Afrique Centrale Evaluées par Télédetection, or "Monitoring the forests of Central Africa using remotely sensed datasets".

[95] Observatoire Satellital des Forêts d'Afrique Centrale, http://www.osfac.net/

[96] This was estimated by dividing the balance of emissions and removals in the GHGI's category changes in forests and other woody biomass stocks into harvest losses and into gains from increment.

[97] This was estimated using the implied removals from forest regrowth as a point of departure, and comparing against the total forest area in 2000 and 2010.

forest frontier, where fire may occur during deforestation events. FAOSTAT[98] reports, for DRC, that between 1.6 to over 2.2 Mha of humid tropical forest has burned each year in the past 10 years, creating CH_4 and N_2O emissions of 18 to 23 $MtCO_2eq$ per year. This value is ten times higher than the TNC's reported non-CO_2 emissions at less than 2 $MtCO_2e$ per year, and therefore underestimation may amount to around 20 $MtCO_2eq$ per year.

Fuelwood harvesting constitutes an important source of emissions, which the TNC estimates at 75 and 98 million m^3 in 2000 and 2010, based on FAOSTAT and a projection. For deriving emissions, three further factors are required: an estimate of wood density (usually around 0.6 t d.m. per m^3 [99]), the ratio between biomass below and above the ground (arguably around 0.24[100]) and an expansion factor for not usable tree parts (arguably around 1.44[101]). Integrating these would lead to expect a biomass loss around 1.07 t d.m. per m^3 for each m^3 of fuelwood collected, but the TNC's calculations estimate the biomass loss as high as 1.75 t d.m. per m^3. If the applied factors were too high, then this may lead to the potential overestimation of emissions from fuelwood harvesting by up to 93 and 122 $MtCO_2eq$ in 2000 and 2010.

Regarding timber, the TNC explains that data on harvested quantities of wood were available from official sources only and potentially significant emissions from informal activities were excluded. A recent study (Lawson, 2014) estimated that actual wood extraction amounts to approximately eight times official statistics; however, logging levels are relatively low such that neglected emissions would amount to only approximately 1.4 and 3.9 $MtCO_2eq$ per year in 2000 and 2010.

The TNC does not indicate inclusion of legacy emissions and removals or the impact of CO_2 fertilization and nitrogen deposition, when making estimates of emissions for the GHGI. Further, there are no indications in the TNC that it includes emissions and removals from peat, although Wetlands International (2009) estimated drained peatlands in the DRC emit 2.4 $MtCO_2eq$ per year in 2008.

	Forest-related category coverage		
	F > NF	F > F	NF > F
TNC (2015)	• Forest and grassland conversion	• Changes in forests and other woody biomass stocks (harvests, fuelwood collection, increment)	• Increment in plantations • Abandonment of managed lands

Pools and Gases: The TNC reports emissions from deforestation from above-ground biomass but it is unclear whether the estimates include other pools. It may be surmised that not all carbon pools are included. For example, dead wood likely was excluded since no default factors are available. Although the TNC does not explain this, it may be inferred that changes in soil-carbon stocks were included because the numbers reported in other GHGI categories do not otherwise sum up to the totals. The TNC includes non-CO_2 emissions, although probably only from burning during deforestation events (see above).

Uncertainties

The DRC's GHGI does not provide any calculation of the level of uncertainties in estimates of emissions and removals.

[98] FAOSTAT report on burned areas in forests based on GFED4 data.
[99] IPCC default wood densities for tropical tree species in Table 4.13 of Volume 4, 2006 IPCC guidelines.
[100] IPCC default root-shoot ratios in Table 4.4 of Volume 4, 2006 IPCC guidelines.
[101] IPCC BCEFR default in Table 4.5 of Volume 4, 2006 IPCC guidelines.

Comparison of national reporting to independent studies

The TNC's emission estimates from forest land converted to non-forest land are less than half of what other independent data sources would suggest, and emissions in forest land remaining forest land are orders of magnitude lower (see table below).

Aggregate emissions and removals in top-level GHGI categories from several sources.

<table>
<tr><td></td><td colspan="3">2000-2010 average net emissions and removals in tCO_2eq per year</td></tr>
<tr><td></td><td>F→NF</td><td>F→F</td><td>NF→F</td></tr>
<tr><td>TNC</td><td>77,628,500</td><td>1,517,000</td><td>-269,154,000</td></tr>
<tr><td>GFW</td><td>198,400,000</td><td>N.A.</td><td>N.A.</td></tr>
<tr><td>Houghton</td><td>184,259,815</td><td>21,405,670</td><td>Not disaggregated</td></tr>
</table>

It is worth noting that the TNC estimates emissions from F→NF about 40% lower than either GFW or Houghton. The Table below shows that underlying estimates of deforestation areas are close, which would lead to expected similar emission estimates. Further below, however, the Figure shows how the TNC's GHGI implies a carbon density much lower than any other source, including those used in GFW and by Houghton. In summary, differences in emission estimates from F→NF seem explainable with reference to emission factors used.

According to the TNC, regrowth in fallows (so-called abandonment of managed lands) is the single most important source of emissions or removals in the DRC's GHGI. It averages 269 $MtCO_2eq$ in removals in 2000-2010, far larger than the country's total amount of emissions and removals. Other sources do not disaggregate this data item and it cannot easily be compared, nor does the TNC explain in detail how estimation was undertaken. By way of comparison, the estimated biomass regrowth corresponds to over 40 years' worth of deforestation areas, which seems unreasonably high. Further below, it is discussed how stripping out such removals from fallow regrowth helps reconciling the TNC's national GHGI with independent estimates.

Deforestation area: DIAF has recently published updated deforestation estimates. The annual deforestation rate was estimated at 0.30% for the time period 1990-2010 and at 0.37% and 0.52% for 2000-2010 and 2014-2014, respectively. These estimates are much higher than any previous official numbers, including those reported to the FAO's FRA and the TNC's GHGI (see Table below).

Several estimates of the DRC's annual deforestation rate

Based on DIAF (2015, 2016), including further sources and own calculations

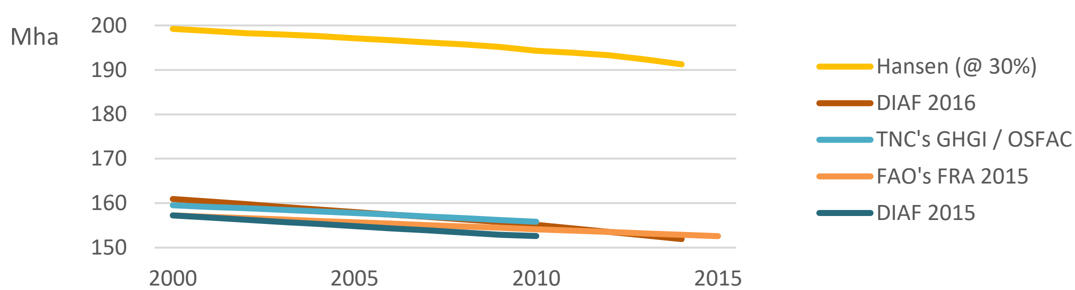
<table>
<tr><th>Source</th><th>1990-2000</th><th>2000-2005</th><th>2005-2010</th><th>2010-2014</th></tr>
<tr><td>OSFAC (not dated) through FACET (used in the TNC)</td><td>-</td><td>0.22%</td><td>0.25%</td><td>-</td></tr>
<tr><td>DIAF 2015</td><td colspan="3">0.30% ± 0.04%</td><td>-</td></tr>
<tr><td>DIAF 2016</td><td>0.17%</td><td colspan="2">0.37%</td><td>0.52%</td></tr>
<tr><td>FRA 2015</td><td>-</td><td colspan="2">0.20%</td><td>0.20%</td></tr>
<tr><td>GFW (Hansen)</td><td>-</td><td>0.21%</td><td>0.28%</td><td>0.40%</td></tr>
<tr><td>Tyukavina et al 2013</td><td>-</td><td colspan="2">0.34% ± 0.03%</td><td>-</td></tr>
</table>

Some discrepancies in deforestation area estimates may be due to definitional issues around crown cover thresholds. Most datasets apply a 30% crown cover threshold for defining forests in line with the national forest definition. But DIAF (2016) applies a 10% crown cover threshold, and indeed it detects much more deforestation area in 2000-2010 than either OSFAC's FACET data used in the GHGI (OSFAC, not dated) or Hansen's data (or in fact DIAF 2015).

Largely, though, the deforestation estimates in the TNC's GHGI, based on the FACET work (OSFAC not dated), compare well to estimates of deforestation rates from some independent sources, notably to data from Hansen (although it refers to a slightly larger forest area, see following paragraph). The University of Maryland is an important partner in OSFAC's FACET project that developed the TNC's deforestation estimates, and indeed both sources rely on similar methodologies, although only OSFAC can be expected to have access to local training data. Deforestation estimates by Tyukavina et al (2013), also from the University of Maryland, that were specifically developed for the DRC and the recent estimates by DIAF (2015, 2016) of deforestation area, are higher than those in the TNC. Such estimates may be higher because of a combination between different crown cover thresholds, minimum mapping units and data periodicity.

Hansen's datasets identify forest areas about 25% higher than the other sources (see Figure below). Although the datasets are all largely based on Landsat images, they apply different minimum mapping units, not always in line with the DRC's official threshold of 0.5 ha as minimum area for forests[102]. The Hansen dataset uses the full Landsat resolution (i.e. a single pixel), identifying small vegetation patches of 0.09 ha as 'forest', but OSFAC (not dated), and DIAF (2015, 2016), apply varying minimum mapping units between 0.36-0.81 ha, lowering forest area estimates. A recent study on the DRC's fragmented landscape with slash-and-burn agricultural systems, has shown large areas to be covered by vegetation at small patches, contributing to the observed differences in total forest area estimates[103].

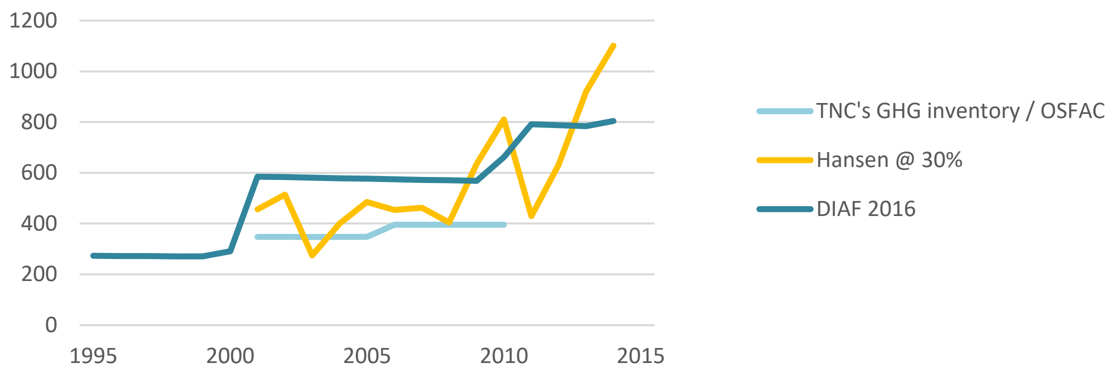
Forest area estimates from several sources



Another potential source of discrepancy is that datasets with longer mapping intervals (e.g. land cover assessments at 5-year intervals) in reality present *net* forest cover losses during those periods, which decreases estimates. Notably, Hansen calculates (gross) tree cover losses on an annual basis, while OSFAC's FACET data used in the GHGI presents net deforestation estimates over a 5-year period, which not only reduce volatility in measurements but also reduces overall deforestation area estimates compared against annual measurements (see Figure below). Much of the short-term gains and losses in tree cover may be related to slash-and-burn agriculture with dynamic tree cover. Because of this, summing the annual forest loss estimates (according to Hansen) will exceed the average forest loss estimate (according to OSFAC not dated). Although the same data periodicity issue applies, DIAF (2016) data are still higher than both other sources for most years, arguably because of a different forest definition (see above).

[102] According to Resolution 5094/CAB/MIN/ECNVT/JEB/08 from 22 October 2008, the DRC's forests comprise vegetation >0.5 ha with a crown cover >30% and tree height >3 m.
[103] The recent work by Tyukavina et al. (2013) on the DRC's forest area would suggest 35% higher deforestation when considering small patch sizes.

Deforestation area estimates from several sources (thousand ha)

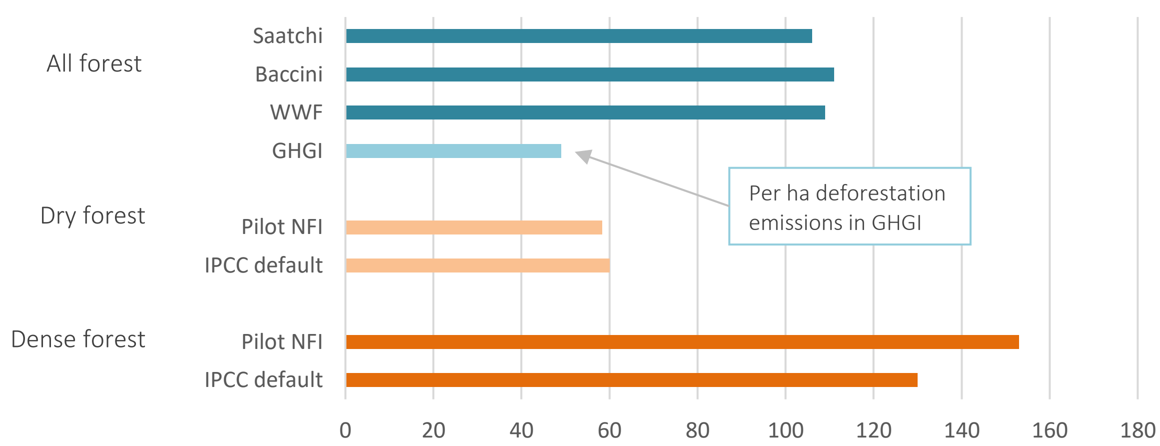


The forest loss estimates according to Hansen are highly volatile for the years 2010-2012. Those are the last years where Landsat 5 was still operational to complement faulty Landsat 7 imagery that suffered from a scan-line correction failure since 2003. (Landsat 6 never operated successfully.) Such data collection issues may compromise reliability of Landsat-based forest loss mapping before Landsat 8 became active in early 2013, providing continuity with earlier imagery.

Biomass density estimates: The TNC's GHGI does not specify the emission factors used, but implies per-ha deforestation emissions of approximately 49 tC per ha in above-ground biomass[104]. The value is much lower than the results of several independent studies that estimate biomass from remote sensing data, arriving at quite similar values (Saatchi et al. 2011; Baccini et al. 2012, WWF 2017). Although it should reflect the DRC's average forests, it is also lower than IPCC default values and field measurements for both dry forest and dense forests (see Figure below). The observed discrepancy is confusing because the TNC also suggests that deforestation emission factors were derived from IPCC default biomass densities for the forest types occurring in the DRC, reconciling the numbers would require unusual assumptions on wood utilization in deforestation or on burning during deforestation.

Comparison of estimates of forest carbon density in the DRC

Above-ground biomass estimates from several sources for dense forest, dry forest and all forest



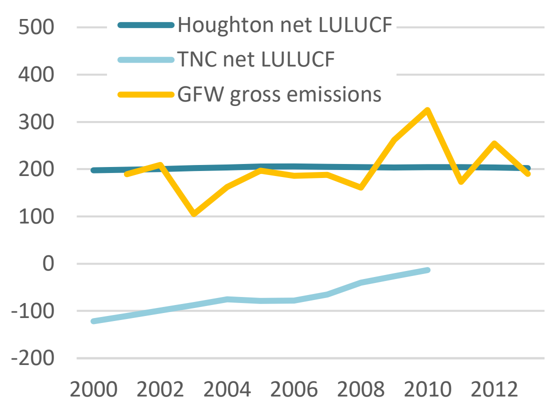
[104] This was estimated using the annual deforestation emissions, deforestation area and default assumptions on post-deforestation biomass stocks and root-to-shoot ratios.

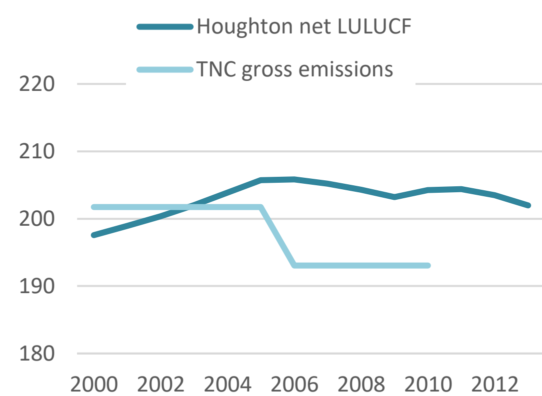
Recently, DRC has published the results of a pilot study for a national forest inventory, representing the first ever appraisal of forest structure through field measurements at a national scale. The small number of plots does not allow for deriving a robust average biomass estimates, but the breakdown of estimates by forest types with higher and lower biomass density does not contradict the IPCC defaults.

Total emission estimates: Given the many disparities in methodologies and approaches used in the TNC versus other studies, it is not surprising that the TNC's total land-use emission and removal estimates differ substantially from GFW and Houghton calculations in both magnitude and trend (see Figure below). The TNC shows a net sink of up to 120 MtCO_2eq in 2000 that reduces to almost zero in 2010. Houghton estimates net emissions of around 200 MtCO_2eq that are essentially flat over 2000-2010. Although it only represents forest cover loss and neglects all other forest-related emissions and removals, GFW is closer to Houghton estimates, showing a source of emissions, fluctuating around 200 MtCO_2eq. Inter-annual variation in the GFW data is much higher because the estimates assume abrupt carbon-stock changes while Houghton's bookkeeping model distributes emissions over decades when they slowly occur.

Comparing net forest flux estimates (MtCO_2eq) of the GHGI vs. independent data sources

Left: TNC's net land-use related emissions and removals vs. other data; right: TNC's gross emissions vs. Houghton's net estimates of emissions and removals.





The TNC's emission estimates are, however, much closer to independent data from Houghton, if only gross emissions are considered (and removals are stripped out, see Figure on right above). There are some doubts regarding the removal calculations (above text on growth in standing forests and text on fallow regrowth), which might go to explain why excluding the national GHGI's removals helps reconciling with independent data sources. Incidentally, the data underlying the DRC's NDC seem to only reflect gross emissions and neglect the removals (see following section).

DRC's Intended Nationally Determined Contribution

The DRC submitted an intended nationally determined contribution (INDC) in August 2015 during the preparatory phase to the Paris Agreement. Ratification occurred in April 2016 and in absence of updates, the INDC reflects the DRC's mitigation objectives. The INDC information on business-as-usual emission trends is closely related with information contained in the TNC.

Overall, the INDC lays out a mitigation target of 17% below business as usual in 2030 or about 77.3 MtCO_2eq. From charts included in the INDC, the mitigation target from land-use related activities may amount to around 25% below business-as-usual in 2030, or about 100 $MtCO_2eq$ (higher than the aggregate national target and thus leaving room for emission growth in other sectors). However, a set of listed mitigation activities with expected emission reductions implies a mitigation target of only 57.7 $MtCO_2eq$ for land-use activities (which would require additional mitigation in other sectors). It is not clear how these scenarios reconcile with each other.

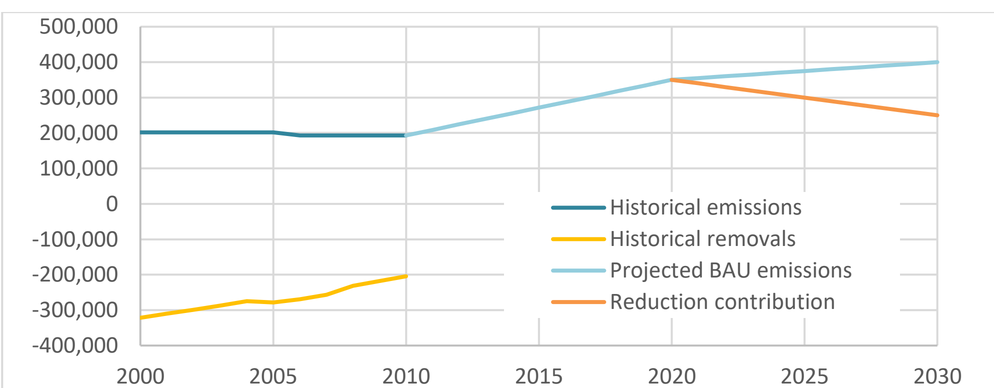
A wide range of land-use activities are expected to contribute to mitigation that are relevant for deforestation, forest degradation and reforestation. The INDC mentions planned activities for tree planting, sustainable logging, mine rehabilitation, fight against grassland burning, intensification of agriculture and livestock, subsistence and small-scale agriculture, industrial fuelwood plantations, improved cooking stoves and high-efficiency charcoal kilns. In terms of policy efforts, the REDD+ programme is specifically mentioned, although the INDC does not detail how accounting for REDD+ and the INDC relate to each other.

The projection of business-as-usual land-use emissions almost double in 2011-2020, and then further increase at a slower pace until 2030. Generally, the expectation of rapidly increasing emissions is in line with dynamic socio-economic trends including rapid demographic change and economic growth, which the TNC explains in detail. Although such trends cannot be inferred from the GHGI that depicts essentially flat emissions for 2000-2010 (based on the OSFAC deforestation estimates (OSFAC (not dated) and referencing the recent DIAF (2015) data), or rising slightly when including removals, some independent sources (e.g., Hansen et al. 2013, DIAF 2016) show accelerating deforestation after 2011.

In depicting historical GHGI trends for land use, the INDC only reflects emissions and neglects removals, even though the TNC estimated these to be rather significant, more than outweighing emissions in most years (although, as explained above, the methodologies in such estimations require improvement). The INDC does not provide an explanation on the rationale for excluding removals. It is difficult to reconcile the exclusion of removals with the expectation, as stated in the INDC, that forest plantations would contribute to mitigation.

DRC's projected BAU emission trends and reduction contribution in its INDC

The INDC suggests an implicit 25% reduction objective below business-as-usual in 2030 for the land-use sector.



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India

India has great geographic diversity, and a variety of climate regimes and thus many different forest types. Its forest cover is over 70 Mha according to the State of Forest Report 2015, equal to 21% of India's total land area and increasing since 1990. The first Biennial Update Report (BUR1) submitted in 2016 includes the most recently submitted national GHGI with the reporting year 2010. The GHGI includes total emissions of 2.14 GtCO_2eq excluding LULUCF and 1.88 GtCO_2eq including LULUCF. According to the BUR, land use is a net sink of -252.5 MtCO_2eq with the category Forest land contributing -200.0 MtCO_2eq or 9.3 percent of total emissions excluding LULUCF.

India is unique among developing countries, not only because it's forest area has been increasing for nearly three decades, but also that it has a repeated NFI that allows for estimates of carbon stock changes in forests over time. However, the national GHGIs may overestimate the actual removals from afforestation due to a lack of data on carbon stocks in all land use categories which has led to a calculation of carbon stock changes on afforested lands assuming that the previous C stock was zero (which can cause significant errors, particularly for soils). This may have an impact on the estimated contribution from forests stated in the country's NDC.

India's reporting to the UNFCCC

India has submitted two National Communications to the UNFCCC in 2004 and 2012 covering the inventory years 1994 and 2000. Furthermore, India has submitted its first Biennial Update Report in 2016 covering the inventory year 2010. India has not yet submitted a FREL/FRL to the UNFCCC.

India has used IPCC guidance including the Revised 1996 Guidelines, 2000 Good Practice Guidance and elements from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and the 2003 Good Practice Guidance for LULUCF. A consistent time series inventory of GHG emissions has been created for the period 2000-2010.

What forest fluxes are included in the GHGI?

Forest definition: India uses tree cover rather than land use for its forest definition. Forest is defined as land with a tree crown cover of minimum 10% and a minimum area of 1 ha. The definition includes all areas with a crown cover and area size above the minimum thresholds regardless of the origin, species and land use.

India reports on emissions and removals from all forest lands based on the tree cover definition and thus implicitly considers all forests managed, however, a definition of managed forests is not provided. India also monitors trees outside forests and the total area of forests and tree cover. The latest State of the Forest Report 2015 includes a forest area of 70.17 Mha (21.3% of the land area) and a tree cover area of 9.26 Mha (2.8% of the land area). Tree cover outside forests is land with trees smaller than the 1 ha threshold.

Forest-related categories covered by the NC2: While the BUR1 provides the most recent GHGI covering the year 2010 it is, as required by a BUR, an update of the Second National Communication (NC2) and provides only information on the overall land use categories: Forest land, Cropland, Grassland and Settlements. The NC2 on the other hand covering the inventory year 2000 presents the GHGI with the structure following the IPCC 1996 Revised Guidelines with the activity Change in Forest and other Woody Biomass Stocks but provides also information on the land use categories: forests land remaining forest land, land converted to forest land, cropland remaining cropland, and land converted to cropland as recommended in the 2003 Good Practice Guidance for Land Use, Land Use Change and Forestry and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

However, not all sub-categories are included and neither the BUR nor the NC report separately on emissions and removals from the category forest land to non-forest. The NC2 provides activity data for the area subject to conversion from non-forest to forest land and forest land remaining forest land and associated emissions and removals.

	Forest-related category coverage		
	F -> NF	F -> F	NF -> F
NC2 (2012) covering the year 2000	Emissions from conversion of land to cropland and land to settlements are included but most likely deforestation is included together with afforestation as a net gain in forest area.	All forest land has been identified using the Indian Remote Sensing (IRS) data (LISS II, LISS III and AWiFS). Emissions and removals have been estimated based on forest cover and forest types combined with NFI data.	All areas of afforestation for the period 1994-2004 have been identified using the Indian Remote Sensing (IRS) data (LISS II, LISS III and AWiFS).
BUR1 (2016) covering the year 2010	Builds on the same methodology as NC2 (above) but includes less detail.		

The same approach has been used for both the NC2 and the BUR1. Activity data are generated by a wall-to-wall mapping based on satellite images identifying forest land remaining forest land and land converted to forest land.

Emission factors have been produced for the different forest types based on data from the National Forest Inventory (NFI) and emissions and removals from forests are estimated by comparing carbon stocks at two different points in time (i.e. the stock-change approach).

However, there seems to be a significant overestimation of removals from afforestation. According to the NC2 (table 2.10 and 2.11) estimates of carbon stock change on areas with afforestation (3.89 Mha between 1994 and 2004) assume there was no carbon on these areas prior to afforestation. Especially for soil carbon this results in very high annual removals (NC2, table 2.11 is reproduced below).

All figures in MtC	Carbon stocks in forest land in 1994	Carbon stocks in forest land remaining forest land in 2004	Net change	Annual change	Carbon stocks in land converted to forest land in 2004	Annual change in land converted to forest land	Total annual change
AGB	1784	1983	199	19.9	118	11.8	31.7
BGB	563	626	63	6.3	37	3.7	10.0
Dead wood	19	24	5	0.5	1	0.1	0.6
Litter	104	114	10	1.0	7	0.7	1.7
Soil	3601	3542	-59	-5.9	211	21.1	15.2
Total	6071	6289	217	21.7	375	37.5	59.2

The accumulated net annual removals from forest land remaining forest land and non-forest converted to forest land reported in the NC2 GHGI is -217.4 $MtCO_2$, which is derived from the table above: 59.2*44/12=-217.1 $MtCO_2$ of which the soil carbon pool from afforestation contributes 35.6%. Because other land uses have not been included in the reporting, and new land for afforestation is taken in as having zero carbon before the afforestation, there is an overestimation of the removals in the year of afforestation. If the change in soil carbon from non-forest to forest is instead estimated to be zero (as a simplification), forest land removals in the NC2 would be reduced from the current level of -203.7 $MtCO_2eq$[105] to -126.3 $MtCO_2eq$.

Data sources: For the Second National Communication, the Forest Survey of India (FSI)[106] produced the publication: Carbon Stocks in India's Forests covering the period 1994 to 2004, which explain the full process of compiling the GHGI for forests related emissions and removals. The information provided below is from this publication unless stated otherwise.

For activity data forest were classified into 15 different group types and combined with three crown density classes:

- Very dense forest with crown cover > 70%;
- Dense forest with a crown cover between 70 and 40%; and
- Open forest with tree cover between 10 and 40%.

Together this provides 45 different classes. Activity data was generated using GIS technologies comparing images from 1994 to 2004.

Data from the NFI was used to produce emissions factors for the different forest classes. India's NFI is compiled by sample plot measurements covering 10 percent of India organized by districts every two years. Using NFI data, it was possible to develop emissions factors for both 1994 and 2004. The NFI provides data on above ground biomass, below ground biomass (mostly by using root to shoot ratios), dead wood, litter and soil carbon.

By combining the geographic location of each NFI sample plot with maps of the 45 different classes, identified changes in carbon stock were calculated for each carbon pool[107].

The FSI produces a State of the Forest Report biennially based on data from the NFI combined with satellite images. Forest inventory data have been collected since 1965 and under the NFI Program, FSI has conducted a NFI since 2002. According to the BUR1 approximately 80% of the country's forests have been inventoried. Besides monitoring forests, the FSI also has a program to monitor trees outside forests. From 1986 to 1991, the forest cover assessment has been made biennially using Landsat data. Since 1991, the FSI has been using the Indian Remote Sensing (IRS) data (LISS II, LISS III and AWiFS) for assessing forest resources and carbon stocks. Before 2001 this included using a resolution at a 1:125,000 scale (25 ha minimum mapping unit) and since 2001 this was improved to 1:50,000 scale (1 ha minimum mapping unit). This shift in resolution meant special efforts were undertaken for the 1994 data in order to make 1994 and 2004 comparable. This included redoing the 1994 classification and expanding from two density classes (Dense and Open forest) to the three density classes mentioned above.

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[105] The difference to the -217.4 Mt CO_2 above is after N_2O and CH_4 emissions from forest fire are included.
[106] Forest Survey of India is an organization under the Ministry of Environment and Forests: www.fsi.nic.in
[107] More detailed information can be found on the FSI website: www.fsi.nic.in

Pools: All five carbon pools are covered by the GHGI. FSI have also carried out an inventory of harvested wood products, however, the data is not included in the GHGI.

Gases: CH_4 and N_2O emissions from forest fires are included using an equation including burned area, available fuel, combustion efficiency and emission factor dividing the burned area into three fire categories: mild, moderate and heavy forest fire.

Uncertainties

The NC2 includes uncertainty analysis for key categories not including LULUCF and thus does not include any uncertainty analysis for forest-related emissions and removals.

The publication *Carbon Stocks in India's Forests* includes, however, information on uncertainties for the estimates. The forest cover classification has an accuracy of 92 percent. The forest type classification used for the carbon estimates has an accuracy of 88 percent and the standard error percentage of the standing growing stocks at national level from the NFI is about 2 percent. The standard error percentage of dead wood, litter, shrubs, climbers, herbs and grasses is 30 percent, however the contribution of dead wood and litter is only about 3 percentage of the total carbon stock, while the contribution of shrubs, climbers, herbs and grasses is only about 1 percent.

Comparison with independent sources of data and analyses

Forest area and change data: India, in its NC2, BUR and country report to the FAO's FRA, does not provide separate estimates for loss (deforestation) and gain in forest area but instead reports on net land use change. For the reporting period this results in a net gain in forest area. This would, in most cases, lead to an underestimation of emissions as it normally takes some years before removals from one ha of afforestation equals emissions from one ha of deforestation.

Global Forest Watch (GFW), which uses estimates based on remote sensing published by Hansen, estimates tree cover loss based on satellite images. This will detect loss of tree cover also when it is only temporary such as after a forest fire or a clear cut. The same methodology for detecting tree cover and thus tree cover gain and tree cover loss has been used for the NC2 and BUR1—however, as mentioned above, the gain and loss for the GHGI most likely have been reported as a net gain only. The total tree cover was estimated for the year 2000 at 49 Mha by Hansen using a tree cover threshold of 10%, consistent with India's methodology but generating a very different result.

The NC2, BUR1 and FRA data on forest area match very well but there is a significant difference with data published on GFW. Some disparities can be explained by the difference in forest definition—the FSI provides data for both the BUR and the FRA using a tree cover of 10% as forest definition and only provides information on net gain in forest area while Hansen uses a 50% threshold for tree cover for gain and variable tree cover for loss (so loss may be compared at 10% tree cover).

The gain in forest area for FAO FRA is a net gain calculated as the net effect of forest gain minus forest loss and therefore it is not possible to compare with data that assess change in forest area based on separate estimates of forest gain and forest loss. The NC2 and the BUR1 do not specify that gain is a net figure, but this is most likely the case.

	Forest loss	Forest area	Forest gain
NC2 (2000)	Not reported separately	65.13 Mha (in 2007)	0.39 Mha annually for the period 1994 to 2004
BUR1 (2010)[108]	Not reported separately	69.79 Mha	0.29 Mha
FAO FRA (2015 report)	Not reported separately	69.79 Mha (in 2010) including: Very dense forest: 8,350 kha; Moderately dense forest 31,875 kha; Open forest 29,565 kha; Mangrove 428 kha; Other wooded land[109] 4.14 Mha	0.44 Mha annually for the period 2000 to 2010[110]
Hansen et al (2013) and GFW	Annual tree cover loss 86 Kha/year for the period 2001-2015 (10% tree cover)	49 Mha (10% tree cover) in 2000.	Annual tree cover gain 21 kha for the period 2001-2012 (50% tree cover)

GHG data: India's forest removals reported in its NC and BUR (-200 and -204 MtCO_2eq, respectively) compare well, although as described above, it may be an overestimation of the forest sink. If a similar methodology is used to derive a net forest removal estimate from India's country report to the FRA, the figure (-250 MtCO_2eq) again compares well. However, a more realistic method of estimation provides a much smaller sink (-103 MtCO_2eq). Similarly, the analysis by Hougton (based on FRA data) is also a much lower figure compared to the BUR and NC.

It is not possible to compare the emissions estimated from deforestation by GFW (using Hansen and WHRC/Baccini) for the period 2001-2015 with the estimates India reports to the UNFCCC since India has not yet reported emissions in the category forest to non-forest (but rather includes everything under one broad Forest Land category). Also, GFW does not include estimates of sequestration from F->F or NF->F.

Source	F→NF	F→F	NF→F
BUR1 (2010)[111]	-200.0 MtCO_2eq		
NC2 (2000)[112]		-66.2 MtCO_2eq	-137.5 MtCO_2eq
	Total net removals: -203.7 MtCO_2eq		
FAO FRA (2015) for the period 2005-2010	-250 MtCO_2/yr (using same methods as the NC and BUR)[113] -144 MtCO_2/yr (assuming soil carbon increase is zero)[114]		
Houghton for the period 2009-2011		-34.28 M MtCO_2/yr	-0.6 MtCO_2/yr
	Total net removals: -34.9 MtCO_2/yr		
GFW for the period 2001-2015	26 MtCO_2/yr		

Note: The difference between CO_2eq and CO_2 depends on whether non-CO_2 forest fire emissions are included or not. However, this does not change the numbers significantly.

[108] BUR1 forest area and forest area gain are from the publication: India State of the Forest Report 2011 and 2013.
[109] Other wooded land is land with a tree cover that is larger than 0.5 ha and less than 1 ha.
[110] Calculated as the difference between the forest area in 2000 and 2010 divided by 10.
[111] The BUR1 provides an estimate for the category Forest land only.
[112] The NC2 provides estimates for forest land remaining forest land and land converted to forest land. The latter is likely to include the net gain in forest area.
[113] The -205 MtCO_2/year is calculated using the change in forest carbon stocks and thus not subtracting carbon already on the land at the time of afforestation which is comparable to the calculations done for the NC2 and BUR1.
[114] The -144 MtCO_2/year is only for illustration purposes calculated by disregarding any increase in soil carbon. Increase in soil carbon constitutes 42.5 percent of the total removals when calculating the 250 MtCO_2/year, which seems to be an overestimation. Subtracting carbon stocks especially soil carbon, present on land before an afforestation event will most likely generate a result significant less than the 250 MtCO_2/year.

Fire emissions: Both the NC2 and the BUR1 include emissions from forest fire. This is based on IPCC methodologies classifying forest fires into mild, moderate and heavy forest fires with differences in ton biomass burned per ha. For the year 2000 these emissions amounted to 552.38 Gg CH_4 and 6.74 Gg N_2O and for 2010 153.02 Gg CH_4 and 1.87 Gg N_20. India has used the Global Warming Potentials from the IPCC Second Assessment Report. With 21 for CH_4 and 310 for N_2O this equals 13.69 Mt CO_2eq for 2000 and 3.79 Mt CO_2eq for 2010 respectively. In comparison, the Global Fire Emission Database (GFED4 reported on FAOSTAT) estimates forest fire emissions from Indian forest in 2000 at 1.55 MtCO_2eq and 2010 at 3.36 Mt CO_2eq. These differences are not surprising taking into account the use of different emission factors and different activity data due to the different approaches used for detecting forest fires. While the activity data provided in the NC2 is based on field studies (the method is not mentioned in the BUR1), the GFED4 builds on detection of burned areas by use of satellite images. The FAO FRA2015 report contains some information on numbers of forest fires and this illustrates the large inter-annual variation with 30,892 forest fires in 2009, 13,898 forest fires in 2010 and 29,362 forest fires in 2011. The FAO FRA2015 report also contains some information on area burned but only for a few selected years and no information on the severity of these forest fires, and therefore it is not possible to compare with the estimates above.

What's included in the nationally determined contribution?

India ratified the Paris Agreement on 2 October 2016 and the Indian INDC, now an NDC, includes a list of eight contributions of which one is to create an additional carbon sink of 2.5 to 3 billion tCO_2eq through additional forest and tree cover by 2030. Additional in this context means additional tree cover in other lands and enrichment of existing forests. It is assumed that the forest and tree cover contribution is an accumulative contribution for the period 2021-2030 as India states its INDC is for the period 2021-2030. The corresponding annual carbon sink targets for a 10-year period would be 250-300 MtCO_2eq per year, as high or higher than all recent estimates and suggests accelerated action.

It is worth noting that the NDC target includes both forest and tree cover, which means the inclusion of trees outside forests, which (as mentioned above) is monitored by the FSI. The NC2 provides estimates of CO_2 sequestration by above and below ground biomass of trees outside forest and estimates that this contributed 35.6 MtCO_2 in 2000.

According to the NDC, India has increased carbon stock in its forest by about 5%, from 6,621.5 MtC in 2005 to 6,941 MtC in 2013. The NDC further explains that initiatives such as Green India Mission (GIM) aim to further increase the forest/tree cover to 5 Mha and improve quality of forest/tree cover on another 5 Mha of forest/non-forest lands along with providing livelihood support. This is expected to enhance carbon sequestration by about 100 MtCO_2eq annually.

The accounting approach is not mentioned explicitly in the INDC but the above calculations are based on a gross-net approach, which means the actual emissions and removals in the year they are reported, i.e. without comparing removals to a reference level (e.g. net emissions compared to a base year or a projected baseline of expected fluxes).

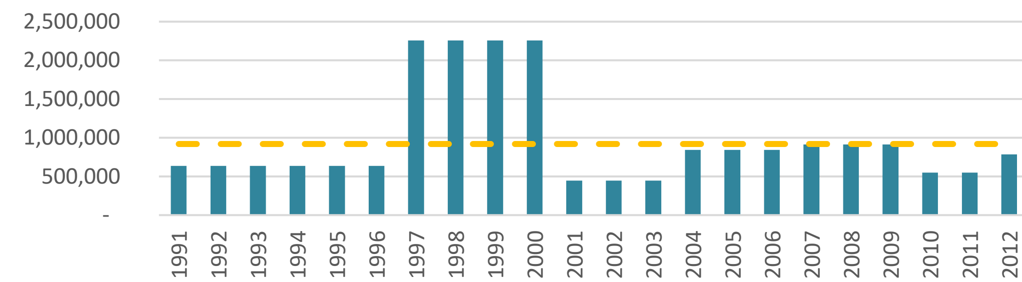
Indonesia

Next to the Congo basin and Amazonia, Southeast Asia's rainforests are the world's third largest tropical forest expanse and Indonesia comprises nearly half of the region's forests. Although several times smaller in forest area, emissions from Indonesia's gross forest loss are nearly equivalent to Brazil's in recent years[115] and its net land-use emissions are likely significantly higher[116].

The land-use sector dominates Indonesia's emissions. According to its first BUR, in 2012 the sector accounted for 48% of total national GHG emissions, mainly from peat decomposition, peat fire, and forest conversion. According to Indonesia's submitted FREL, annual deforested area averaged 919,000 ha per year in 1990-2012, with a strong peak in the late 1990s, when annual deforestation area was more than double the average (see Figure below).

Indonesia's deforestation trends in 1990-2012 (annual natural forest area loss in ha/yr)

Source: Indonesia's FREL (2015)



There is high inter-annual variability, largely due to fire (see Figure below). For example, in 2006 – a dry El Niño year – Indonesia experienced fires on 720,000 ha, with emissions of 510,000 tCO_2eq, while in most other years, burnt areas were closer to 300,000 ha.

Indonesia's GHG emissions from land use and its changes in 2001-2012 (thousand tCO_2eq)

Source: Indonesia's first BUR (2016), Figure 2.60

[115] According to FAOSTAT Brazil's forest is about five times larger than Indonesia's, but forest loss estimates are only about a third higher.

[116] According to the first BUR, emissions from peatland burning are of a similar order of magnitude as those from deforestation. Peatland burning does not occur to the same extent in Brazil.

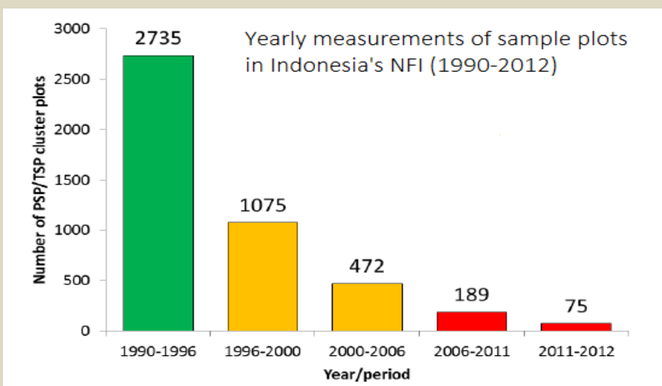
There are many sources of information on Indonesia's forests. The official GHGI is reported by the Ministry of Environment and Forestry. Its Forestry Research and Development Centre also engages in the INCAS project to develop and test methodological approaches for future improvement to the land-use GHGI. For benchmark information on forest biomass density, Indonesia conducts an NFI. Data on Indonesia's forests have also been published by numerous independent sources, including on forest-cover change by researchers at the University of Maryland and on the quantification of forest biomass, including by Saatchi et al. (2011) and by Baccini et al. (2012). WRI's Global Forest Watch draws on combinations of these.

Indonesia's reporting under the UNFCCC

Indonesia has developed three National Communications (two submitted in 1999 and 2011, and one expected for 2017). Indonesia also submitted one BUR (in 2016) and one FREL (in 2015), which both underwent a technical assessment / analysis process. Indonesia's FREL submission provides the country's most transparent reporting on land-use emissions to date. The submission is designed to specify all methodological steps to a point that enables independent recalculations. Although gaps remain, for example regarding peatland fires, these are clearly identified and illustrated, including their magnitude. Also, the first BUR includes more detail than many other developing countries' BURs.

However, coherency of estimates between successive iterations of the GHGI is relatively low. For example, the BUR compares estimates for emissions from (mainly) deforestation against those included in the Second National Communication (SNC) for the years 2000-2006 and finds differences ranging from 20-900 $MtCO_2eq$ per year and averaging 307 $MtCO_2eq$ per year (BUR, Table 2-26). The discrepancies are largely due to the use of different underlying estimates of forest loss and of peatland fires.

Indonesia's reporting to the UNFCCC suggests technical capacity gaps including compliance with applicable IPCC guidance. Although the most recent reports employ the current 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement, the FREL assessment report points out several issues with following such guidance, for example the treatment of post-deforestation biomass regrowth (assumed to be zero) and the use of land-cover versus land-use based definitions. An important underlying reason for capacity gaps and challenges to data quality may be discontinuity and funding gaps in data collection campaigns. For example, the level of effort invested into the NFI dropped dramatically since the 1990s (Figure below) and remeasurements have not yet been possible.



Source: Tatang Tiryana, presented at Review of Methodology of National Forest Inventory Workshop, Jakarta, 9 July 2015.

Other functional capacity improvements needed include processes for data harmonization and quality control. For example, the FREL technical assessment report points out that peatland and forest-cover datasets are insufficiently harmonized—leading to surprising results where dryland forests occur on peatlands. It also identified a need for better quality management of data to avoid observed discontinuities in land-use statistics. Cognizant of such difficulties, Indonesia is working under its 'one map policy' to enhance coherency between official geospatial data.

What forest fluxes are included in the GHGI?

The two most recent reports submitted to the UNFCCC are the FREL (late 2015) and a first BUR (March 2016) with a full GHGI. The scope of forest-related coverage differs in these two reports. Despite only limited level of detail in the first BUR, it appears that while the *most* significant emissions are included (e.g. from deforestation and peat fires) in the GHGI, there are also indications that the inventory does not yet cover all significant forest flux components.

Data sources: The first BUR and the FREL are both based on spatially explicit monitoring of forest change through satellite imagery. During the 1990s, data are only available sporadically and draw on a combination of different sensors and interpretation techniques. Only in more recent years, since the opening of the Landsat archive[117], are annual estimates using consistent (Landsat) imagery possible. Both the BUR and FREL estimate forest biomass density from the NFI. Indonesia's NFI was largely implemented in the 1990s. It covers around 4,500 sample plots in a sophisticated sampling design with both temporary and permanent sample plots. Key data sources for estimating emissions from peatland decomposition and peatland burning include the location, extent and properties of peatlands, as well as of fires. A general peatland map is available and information on fire has been collected from the evaluation of MODIS and Landsat imagery.

Forest definition: For the GHGI in the BUR as well as forest-related fluxes in the FREL, Indonesia applies a forest definition that combines criteria related to land cover (notably, a crown cover threshold greater than 30%) with other criteria (notably that regrowth – even after temporary unstocking – is no longer considered forest land). This definition is useful for generating activity from remote sensing. It implies that important regrowth is included under croplands and grasslands, not forest lands, namely in estate crops and in secondary vegetation. It also implies that important emissions occurring on land with temporary loss of forest cover are included in forest land to non-forest land (or deforestation) and not in forest land remaining forest land (or forest degradation) (see below discussion on the INCAS programme).

Forest-related categories covered: The GHGI in the first BUR provides estimates for most forest-related emission and removal categories, although some are incomplete. For establishing emissions and removals in forestland remaining forestland, the first BUR largely excludes disturbances, except for burning of peatlands. Also, CO_2 removals from peatlands are not estimated. These occur when natural peatlands continue growing through accumulation of soil-organic carbon, and may be large but usually not considered anthropogenic and hence not estimated.

The FREL submission is narrower in scope; for example, it excludes: emissions from peat fires (suggesting such emissions are too uncertain to include at this time) even though the BUR suggests these comprise around one-third of land use emissions (BUR, Table 2-24); does not account for forest plantations (limiting the scope to areas that were natural forest in 1990); and does not account for carbon removals from reforestation or forest management (which the BUR estimates at around 5% of land-use related fluxes; BUR, page 2-67). Emissions from forest degradation are quantified based on measurements of degraded forest area (from satellite imagery) combined with estimates of differences in biomass stocks against primary forests. In contrast, the first BUR quantifies emissions from forestland remaining forestland drawing on a combination of statistics on (legal and illegal) logging, fuelwood collection, and increment in degraded natural forest.

[117] https://landsat.usgs.gov/sites/default/files/documents/USGS_Landsat_Imagery_Release.pdf

	Forest-related category coverage		
	F -> NF	F -> F	NF -> F
BUR (2016)	• Forest land converted to non-forest land • Increment in non-FL	• Losses from logging • Gains from increment • Burning of the peatland layer in organic soil, but not forest fire outside peatlands or aboveground biomass in peatland	• Non-forest land converted to forest land
FREL (2015)	• Natural forest loss only • Excludes post-deforestation regrowth in non-forest land	• Forest degradation • Includes peat decomposition, excludes peat fires	• Excluded

Pools: The first BUR, as well as the FREL, mainly estimate emissions in above-ground biomass, excluding other carbon pools, although these are significant. Soil organic carbon estimates represent only peatland decomposition and exclude mineral soils. These may be significant, with default factors suggesting carbon stocks of around 180 tCO_2eq per ha and a reduction of around 50% upon conversion (2006 IPCC Guidelines, Table 2.3 and Table 5.5). For example, for primary dryland forest loss, above-ground biomass emissions would amounts to approximately 488 tCO_2eq per ha (BUR, Table 2-22), and emissions in soil-organic carbon would add an additional 18%. Below-ground biomass also seems to be excluded, and could amount to additional emissions of around 14%, considering information provided in the FREL (or up to 37% of above-ground biomass fluxes if applying standard root-to-shoot ratios (2006 IPCC Guidelines, Table 4.4)). According to the FREL submission (FREL, Annex 3.2), deadwood and litter, also excluded from the GHGI, may contribute an additional 16% of emissions from deforestation. In summary, the excluded carbon pools may add a further 48% in emissions from deforestation, and a further 14% to emissions from forest degradation.

Gases: Emission estimates for the land-use sector in the first BUR include mostly CO_2 and neglect non-CO_2 emissions from peat decomposition and peat fire. For example, regarding peatland decomposition on drained croplands, default factors for non-CO_2 emissions amount to 7 $kgCH_4$ and 13 kgN_2O per ha and year (2013 IPCC Wetlands Supplement, Table 2.3 and Table 2.5), corresponding to about 4.2 tCO_2eq per ha and year, which adds about 8% to the CO_2 emissions for drained croplands (BUR, Table 2-23). Regarding peat fire, default emission factors for methane would lead to expect a mass ratio of 4.5% between tCH_4 and tCO_2-C (2013 IPCC Wetlands Supplement, Table 2.7), which implies that CH_4 emissions amount to about 26% of peatland fire emissions from CO_2, applying CH_4's high global warming potentials.

Managed land proxy: Indonesia's GHGI does not identify 'unmanaged lands'. However, it assumes fluxes for primary forests (dryland primary forests, mangrove primary forests, swamp primary forests) are zero, which delivers the same results as excluding them (e.g. if the country chose to identify primary forest as unmanaged per the IPCC's managed land proxy for estimating anthropogenic GHG emissions and removals). All loss estimates in forestland remaining forestland relate to logging that, by definition, would not originate from primary forests. Also, any forests where emissions from peatland fires occur could, if the definition of 'managed land' was such, fall outside the primary forest class. In summary, not explicitly distinguishing managed from unmanaged lands may not introduce much error into calculations.

Uncertainties reported in the GHGI

Indonesia included uncertainty analyses in the first BUR and 2015 FREL to estimate error in emission factors and in activity data. However, several important sources of uncertainty are not included in the analysis, and could be large. The BUR includes only limited information on the uncertainty of emission factors. The applied default emission factors on peat decomposition come with confidence intervals, and the BUR also provides confidence intervals for forest biomass density estimates. Reported uncertainty is less than 10% for most types of deforestation and less than 20% for most types of forest degradation. However, the FREL submission clarifies that these figures only reflect the NFI's sampling error, neglecting other sources of errors, such as those in allometric equations or in measurements.

The GHGI in the first BUR does not include an accuracy assessment on the extent and location of deforestation and forest degradation. The FREL submission draws on the same principal data sources and includes only a partial assessment of accuracy. Accordingly, the used maps agree with field data in close to 88% of cases for distinguishing forests from any other land and in 70% of cases if distinguishing between primary and secondary forests. While those accuracies may seem reasonable, a far more important metric is not reported: the uncertainty of deforestation and forest degradation area. It may be very difficult to build robust estimates of deforestation area (amounting to about 0.3-0.9% per year) from available data on forest-area change, where uncertainties (around 12% of the area at an 88% agreement) exceed the annual deforestation rate (Figure below).

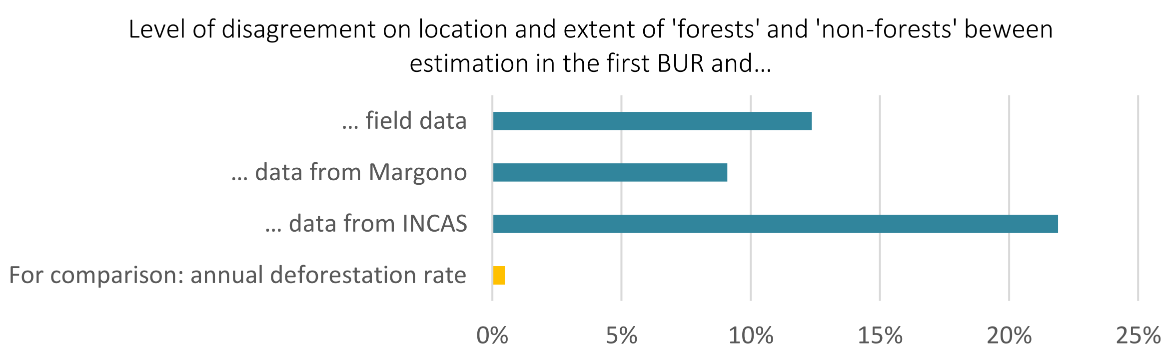
Comparison of national reporting to independent studies

Several sources on aggregate emissions in top-level GHG emission categories do not compare well (Table below). Emissions and removals are generally much lower in the GHGI than in other sources. Only for forest land converted to other land uses do estimates compare well among GFW, INCAS and Houghton, but not with the GHGI. The following discussion aims to understand these discrepancies better.

Aggregate emissions and removals in top-level GHGI categories from several sources.

	2001-2010 average net emissions and removals in tCO2eq per year		
	F→NF	F→F	NF→F
BUR	174,332,700	34,329,500	-2,413,000
GFW	442,700,000	N.A.	N.A.
Houghton	454,540,975	192,146,167	N.A.
INCAS	476,901,300	537,993,500	-8,668,000

Deforestation area estimates: Indonesia publishes estimates of forest-cover change and associated emissions through several channels, relying on diverse methodologies. Next to the first BUR and the closely aligned FREL submission, the Ministry of Environment and Forestry publishes deforestation estimates through its annual statistical yearbook. In addition, data sets are provided by the INCAS project and researchers at the University of Maryland (e.g. Hansen et al. 2013; Margono et al. 2014). There is substantial disagreement among such studies on the location and extent of forests and non forests. The level of disagreement[118] exceeds by far the annual rate of forest-cover change (Figure below).

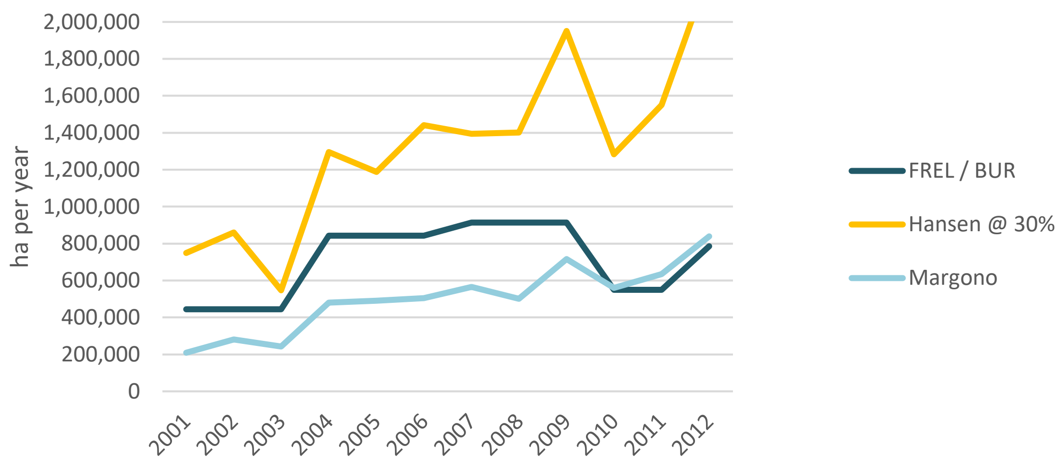


[118] Based on information included in the FREL.

Furthermore, official estimates of forest loss do not compare well with independently generated data sets provided by researchers at the University of Maryland (Figure below). The deforestation definition used in the first BUR and the FREL submission is 'natural forest cover 1990 into any other land-use category'. With this, the GHGI excludes any area that grew back since 1990. Hansen data would cover all vegetation according to its crown cover, including plantations for rubber, palm oil, and timber/pulp. It would also pick up routine harvests and renewals in forest plantations, which the GHGI does not consider deforestation.

The data by Margono et al. (2014), also from the team at the University of Maryland, looks at clearing of both intact and degraded natural forest in 2000, masking out forest plantation areas. In addition, it uses training data drawing on local expertise, while the methodology is otherwise similar to Hansen et al. (2013)'s. Estimates of forest loss are much closer to those in the first BUR and the FREL submission, particularly since 2009[119]. The FREL submission explains that during 2000-2009 mixed data sources included imagery from MODIS and SPOT next to Landsat, which may cause the observed substantial differences.

Comparison of forest area loss in Indonesia's GHGI vs. tree cover loss by Hansen and forest cover loss by Margono et al. (2014)

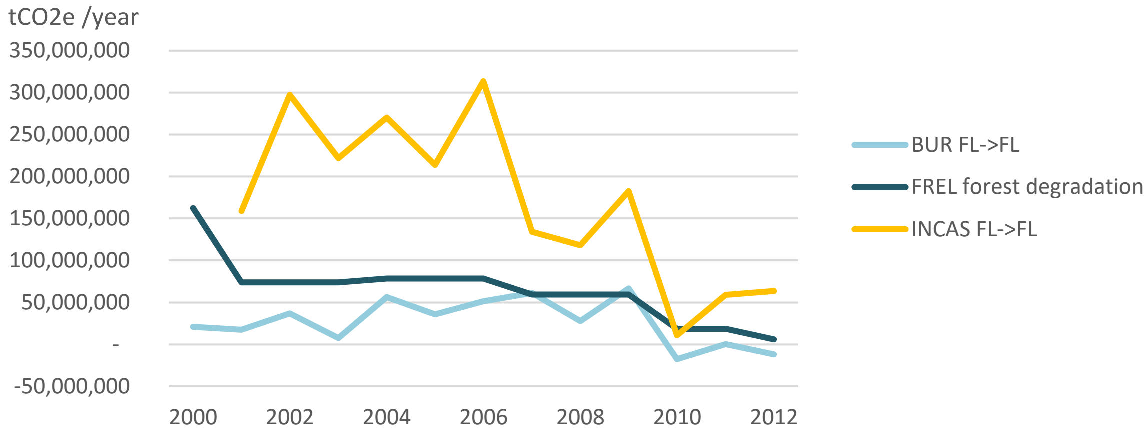


Forest degradation emissions: Estimating emissions in forest land remaining forest land and from forest degradation is notoriously difficult and estimates from several official sources cannot easily be reconciled. The FREL builds estimates from the identification of forest disturbance in satellite imagery. The INCAS project has the same point of departure, but additionally draws on observed fire and logging statistics. Importantly, it includes emissions from temporary unstocked forests under forest land remaining forest land, which the FREL counts as deforestation rather than degradation. The resulting degradation emission estimates from INCAS are higher by orders of magnitude than the degradation estimates from the FREL (Figure below). INCAS estimates that forest degradation emissions exceed deforestation emissions by 13%, dominating Indonesia's emissions profile. The FREL on the other hand detected higher emissions from deforestation than from degradation by a factor of five, with both deforestation and degradation emissions in the FREL much lower than the INCAS estimates.

[119] The BUR and the FREL contain very similar data on deforestation area and area here treated together. While the FREL reports on less frequent measurements, the BUR reports annual estimates that were derived by interpolating between those using data by Margono et al. (2014) to represent inter-annual variability.

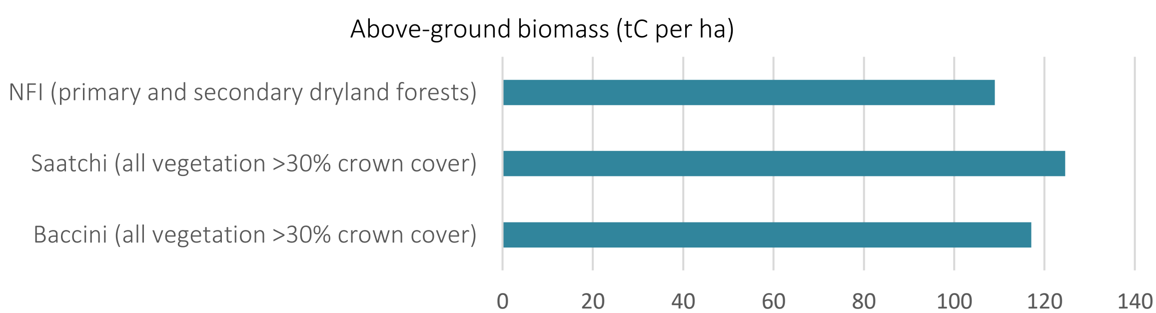
Comparison of emissions estimates in AGB from forest land remaining forest land and forest degradation

INCAS data were corrected to remove the below-ground biomass carbon pool using a default root-to-shoot ratio



The BUR approach to estimating emissions from forest land remaining forest land is entirely different from both the FREL and INCAS, relying on logging statistics and expected forest increment. The BUR explains that illegal (and therefore unregistered) activities outweigh officially recorded statistics. It therefore relies on the Ministry of Forestry's unpublished estimate produced in 2002.

Biomass estimates: The GHGI's biomass estimates are built from Indonesia's NFI that includes several thousand field plots. It measured average above-ground biomass across primary and secondary dryland forests at 109.9 tC per ha (BUR, Table 2-22, converted using default factors). Estimates are slightly lower for swamp forests, and slightly higher for mangrove forests. Remote-sensing based estimates from global studies, such as work by Saatchi et al. (2011) and by Baccini et al. (2012) that represent all vegetation >30% crown cover, are within range of the NFI estimates for primary dryland forests (124.6 and 117.1 versus 125.0 tC per ha), although calibration of remote sensing models is likely skewed towards primary dryland forest (Figure below).



Peatland fires: The first BUR includes estimates of peat fire emissions, which indicate that peatland fires are highly variable and count among the most important emission sources—but uncertainties tend to be very large. The FREL discusses peat fires only in an annex and ultimately excludes emissions because of the large uncertainties surrounding all parameters: hotspot detection, estimation of burned area, fire frequency, burned peat depth, and mass of fuel. The SNC gave a detailed account of various independent studies that have estimated emissions of peat fires (Figure below) concluding that the differences between estimates from different sources are significant. A more recent quantification by the INCAS project, an initiative of Indonesia's Forest Research and Development Centre at the Ministry of the Environment and Forestry, results in estimates that are less than half of those in the BUR for most years. Difficulties in mapping extent, distribution and properties of peatlands and fires are among the causes contributing to discrepancies among estimates. The Government of Indonesia dedicates much current effort to better measuring peat fires and associated emissions[120].

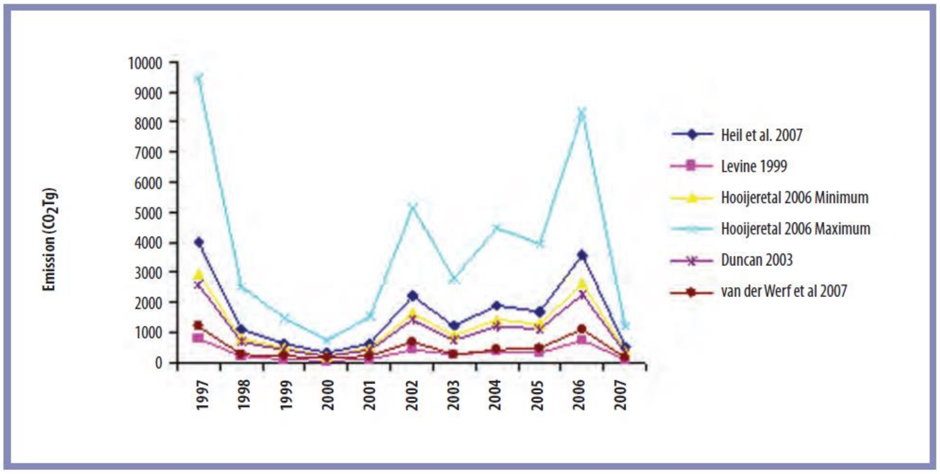


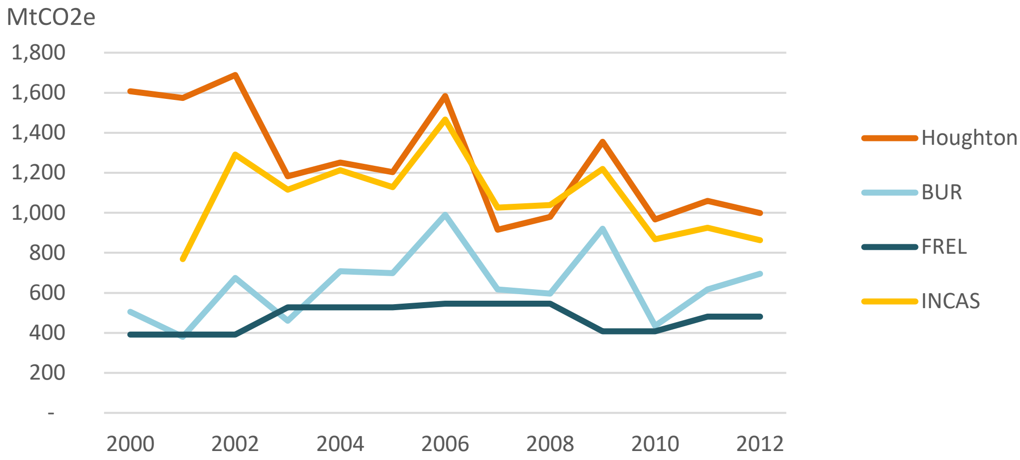
Figure 2.3 Estimate of emissions from peat fires from various studies. Note: Emissions estimates from years beyond the publication date of the reports were made by Aldrian (2008) and Wibowo and Boer (2009)

Total emission and removal estimates: Comparing total emission and removal estimates between Indonesia's official data and the results presented by Houghton yield several observations (see Figure below). First, estimates by the INCAS project are very close to Houghton results. Both are based on a bookkeeping model that tracks land-use change events, resulting carbon stock changes, regrowth and decay processes over time. Second, estimates in the FREL and BUR are also close to each other, with peatland fires, prominent in 2002, 2006 and 2009, arguably making up most of the difference. (The FREL not only excludes peatland fires but also all removals, which introduces further differences). Third, the *trends* in the BUR's estimates and those produced by Houghton and the INCAS project are rather similar, however, the BUR's estimates are about 400 MtCO_2eq per year lower on average.

One reason that may explain why the BUR's emission estimates are lower may be the treatment of legacy effects from higher forest-change rates in earlier years. The GHGI uses a common simplifying assumption that biomass stock changes are abrupt upon land use change. In reality, carbon stock changes occur over decades as vegetation approaches a new equilibrium. Bookkeeping models track the transfer from living biomass to dead matter and its decomposition over time. For example, during the years 1990-2000, forest loss amounted to 1,100 Mha per year, and during 2000-2010 to 800 Mha per year according to the FREL. The bookkeeping models distributes the emissions impacts of high deforestation and forest degradation in the 1990's across a longer period of time, and won't reflect a decrease in loss rates nearly as quickly as the instantaneous emissions approach used in the GHGI, which would explain some if not all of the observed differences.

[120] Including through a recent governmental workshop dedicated to the from emissions peat fires in 2015: http://ditjenppi.menlhk.go.id/berita-ppi/2657-info-brief-understanding-estimation-of-emission-from-land-and-forest-fires-in-indonesia-2015.html

Aggregate emissions and removals from land use according to official and independent sources.



Indonesia’s Nationally Determined Contribution

Indonesia submitted its NDC in late 2016. It reiterates the 2009 target to reduce 2020 emissions against business as usual (BAU) by 26% unconditionally and up to 41% with international support. It also proposes an unconditional target to reduce emissions by 29% against BAU in 2030 and extends the conditional “up to 41%” target to 2030, which projections approximate using a 38% emission reduction scenario. All targets are broken down by the five industry sectors. In terms of the unconditional 2030 target, the forestry sector contributes the largest share of emission reduction at 70% below BAU, corresponding to 217 $MtCO_2eq$ per year, compared to a BAU of 714 $MtCO_2eq$ per year.

The starting point for building mitigation scenarios is the first BUR’s GHGI. The targets make specific reference to several emission sources that are included in the BUR, but excluded from the FREL, such as peat fires. Broad coverage is also suggested by the reference to forest-sector policies for mitigation, where the NDC points to Indonesia’s national climate change action plan—which includes a broad set of mitigation measures relating to the full scope of fluxes included in the GHGI, to its REDD+ programme, including the logging moratorium, and to peat management. The NDC also emphasizes that Indonesia will pursue a landscape and ecosystem management approach.

Indonesia plans to build a transparency framework with five components, which include, separately, a GHGI system and an MRV system for mitigation covering REDD+. The MRV system for mitigation, including REDD+, may be understood to include, inter alia, two data collection and reporting efforts: firstly, the FREL and the BUR technical annex on REDD+ results, and secondly, the monitoring and evaluation framework of the national climate change action plan. Reporting on the NDC targets for the forest sector may draw on a combination of these data collection and reporting efforts next to the GHGI.

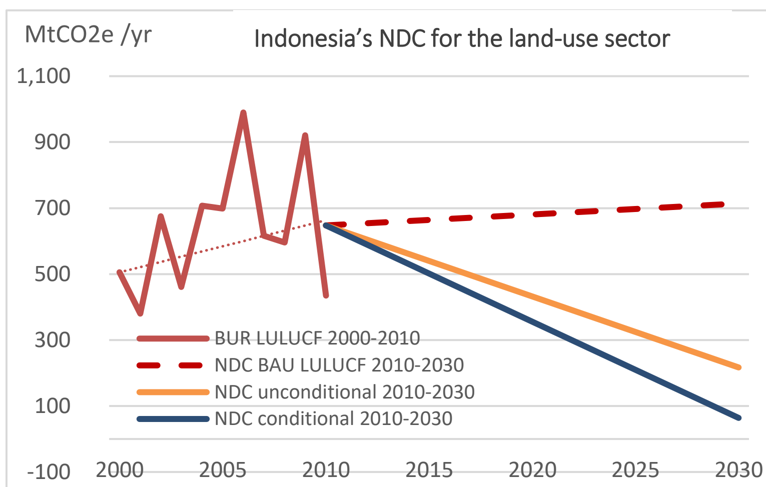
For the forest sector, the national climate change action plan includes an activity-based reporting component for mitigation actions implemented at the subnational level, and a sectoral reporting component at the national level. Both of these have a detailed MRV framework, as well as accounting against BAU scenarios. These frameworks may generate mitigation estimates that differ from the GHGI since they were designed for mitigation actions and not for a wall-to-wall GHGI. The national climate change action plan was specifically set up to achieve Indonesia's 2009 target to reduce emissions in 2020 against business as usual by 26% (and a further 15% with international support). At least for domestic purposes, until 2020, the target might therefore be evaluated using its MRV and accounting framework (as opposed to the GHGI).

The NDC's target setting for the forest sector closely relates with REDD+. The Warsaw framework requires bringing REDD+ reporting in line with the GHGI. Indonesia has chosen to align the NDC's BAU scenario until 2020 to the FREL through using historical average deforestation as a key parameter, and assuming a slight drop in BAU deforestation thereafter from 920,000 to 820,000 ha/year . Many other parameters are also relevant, including on wood production and forest growth. The NDC's BAU emissions increase by about 0.5% annually in 2010-2030. Nonetheless, for future reporting the difference between the GHGI and the NDC's BAU scenario may be expected to closely reflect REDD+ results in a future BUR technical annex on REDD+ results.

The NDC is ambiguous on separating its unconditional vs. conditional (on international support) mitigation contributions. On the one hand, for the forest sector, the 2030 reduction below BAU is expected to amount to a 70% unconditional reduction or a 91% reduction with international support. On the other hand, closely aligning the BAU to the FREL (see previous paragraph) suggests that REDD+ results are part of the unconditional reduction. The NDC discusses, however, an expectation to generate results-based payments from REDD+, which could be understood to include REDD+ results among mitigation to be achieved using international support.

What are trends in emissions and removals?

The reference to BAU anchors the targets against a projected economic scenario and its emissions profile. For the forest sector, the projection relies on a "dashboard AFOLU for land-based sector", a set of assumptions relating to deforestation rates, wood production and mean annual increments in standing forests. Although the NDC fixes specific emission quantities for the targets, it also points to the possible need to revise the BAU scenario in light of future macro-economic development.



Sources

Baccini et al. (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change,* 2: 182-185.

Saatchi et al. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, Vol 108 No.24, 9899–9904. doi: 10.1073/pnas.1019576108.

Margono et al. (2014). Primary forest cover loss in Indonesia over 2000–2012. *Nature Climate Change*, 4: 730–735

Russia

The Russian Federation contains a fifth[121] of the entire global forest area, and the second largest area of peat, 57 Mha[2] (Canada has the largest). Emissions and removals from the Russian forest area have significant impact on Russia's total annual emissions reported to the UNFCCC. According to the most recently submitted GHGI (2017) with the latest reporting year 2015, Russia reported total emissions without Land use, Land Use Change and Forestry (LULUCF) of over 2.65 $GtCO_2eq$, and total emissions with LULUCF of 2.13 $GtCO_2eq$, with net removals from the category Forest Land including HWP of over -589 $MtCO_2$ equal to 22.2 % of the total emissions without LULUCF.

The large amount of removals from the forest sector since 1990 is partly a consequence of a significant decrease in the harvesting rates since 1990, which paved the way for the significant net removals since that period (Zamolodchikov et al, 2011). At the same time this meant a reduction in the inflow to the Harvest Wood Products (HWP) pool making HWP a net source of emissions with average emissions at 21.3 $MtCO_2$/year over the period 2006-2015. Forest fire emissions also have significant impact on overall forest-related fluxes with annual average emissions over the period 2006-2015 at 150.4 $MtCO_2eq$ which can be compared to the net annual average removals from forests over the same period at 798.7 $MtCO_2$ (excluding emissions from fire and HWP).

The distribution of the carbon budget includes a European part of the Russian Federation with annual average net removals higher than 1.0 tC/ha and an Asian part where the annual average removals is less than 0.5 tC/ha. This difference is partly explained by the forest fire regime and the fire control measures that has been implemented more rigorously in the west compared to the east, where forest fires have been allowed to burn unless settlements are threatened (Zamolodchikov et al, 2011).

Russia considers 76 % of its forest area as managed forest. This is one factor that explains discrepancies between independent studies covering all forests and the Russian GHGI. Taking into account that higher temperatures will most likely affect both the extent of the forest area and annual growth rate with longer growth seasons, there are likely significant removals from unmanaged forests. At the same time climate change is also increasing the frequency and severity of pest outbreaks and forest fires in the boreal forests causing increasing emissions as a result (Flannigan et al, 2009). Therefore, the net effect on forest carbon stocks is unclear (Kurz et al, 2013).

Russia's Reporting to the UNFCCC

As with other developed countries, Russia has submitted six National Communications, two Biennial Reports, and 15 National Inventory Reports (2003–2017). It has also submitted a report under the Kyoto Protocol for the first commitment period. Most recent reporting uses the 2006 IPCC guidelines, the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto and the IPCC 2013 Wetlands Supplement.

The Russia Federation estimates forest fluxes based on the activity-based approach (article 3.3. and 3.4) for reporting under the Kyoto Protocol, and the land-based approach for reporting under the Convention. For the purpose of this case study we analyze the reporting that uses the land based approach for the Convention since this is more comprehensive in terms of forest area covered.

[121] FAO Global Forest Ressource Assessment 2015: http://www.fao.org/3/a-i4808e.pdf

What forest fluxes are included in the GHGI?

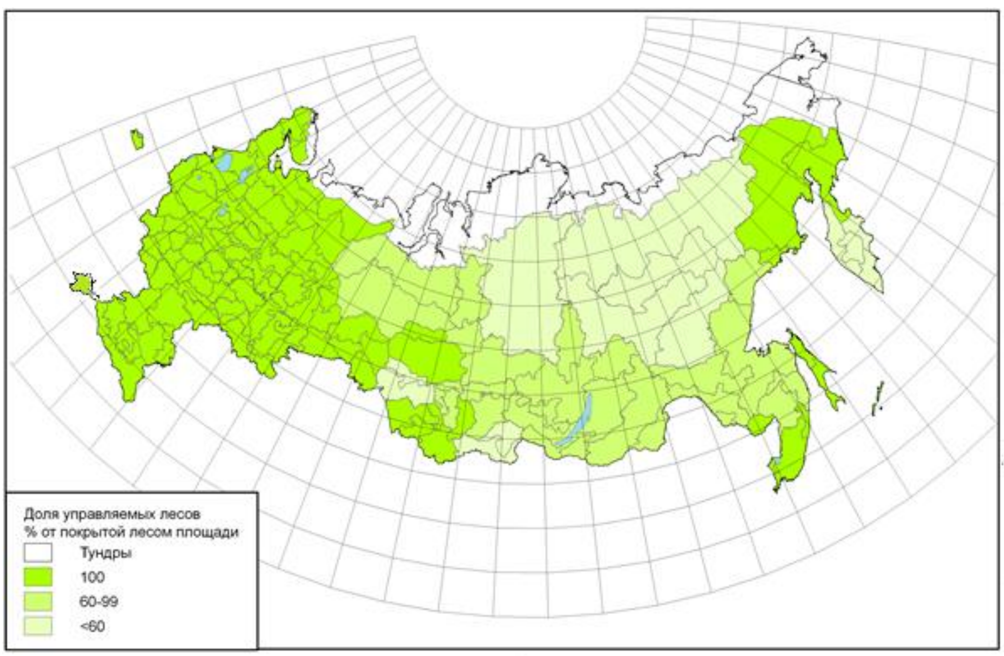
Forest definition and area: In the Russian Federation a forest is defined as a community of trees and shrubs, which at maturity has stand density of 0.3% corresponding to a crown cover of 18 %, minimum tree height of 5.0 m, minimum area 1.0 ha, and minimum width of 20m.

Managed land proxy: The Russian Federation employs the managed land proxy in its National Inventory Report (NIR), separating areas of managed forest versus unmanaged forest (see Figure below). The total forest area reported in the most recent GHGI (covering 2015) is 897 Mha, including 685 Mha managed forest and treating 212 Mha (23.6 percent of the total forest) as unmanaged.

Managed forests are defined 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 any area with an organized set of economic activities in forests such as: conducting of regular forest inventories, long-term planning, determination of annual allowable cut and accounting for their economic purpose and environmental functions, as well as forest protection and reforestation activities that ensure the stabilization and reduction of forest losses from fire and other disturbances.

Percentage of managed forest of total forest area

Source: NIR 2016



Significant land areas have been reclassified over the years and the area of managed forest has increased from 609 Mha in 1990 to 685 Mha in 2015. The managed forest area has increased mainly due to transfer from unmanaged to managed forests, but also increased due to afforestation on cropland while an almost similar area was lost due to conversion to settlements. The unmanaged forest category increased during the same period due to transfers of from the category “other lands” and from unmanaged grassland.

Development in managed and unmanaged forests since 1990 (Mha)

	1990	2015
Managed	609,60	685.12
Unmanaged	168,99	211.89
Total forest area	778,59	897,01
Percentage managed	78 %	76 %

Note: The 2015 area include the Crimean, which is not the case for 1990. This added an additional 0.3 Mha of forest land.

Following IPCC guidance, the GHGI does not report emissions and removals occurring on unmanaged forests. The following emissions and removals occur on unmanaged areas and would not be represented in its GHGI and include:

- Net natural CO_2 removals (net primary production minus mortality/turnover); because of the impact of CO_2 and N fertilization as well as of changes in the temperature regime, this may be a significant sink;
- Emissions and removals due to increases in the unmanaged forest area by natural expansion of forest on unmanaged grassland;
- Emissions from forest fire and pest disturbance;
- GHG fluxes from peatlands, including impacts from permafrost thaw (unclear if source or sink).

Forest-related categories covered: The Russian GHGI reports on all forest categories: forest land to non-forest, forest land remaining forest land and non-forest to forest land.

	Forest-related category coverage		
	F > NF	F > F	NF > F
NIR 2016	Estimates provided for F > Settlements Other possible transitions are reported as not occurring.	This is by far the largest flux in the LULUCF sector Area of unmanaged forest to managed forest is also provided	Estimates provided for Cropland > F Other possible transitions are reported as not occurring. Area of unmanaged grassland to unmanaged forest is also provided.

Pools and gases: The GHGI includes CO_2 emissions and removals from managed forests due to carbon stock changes in living biomass, dead wood, litter and soil carbon in mineral and organic soils as well as CH_4 and N_2O from drained forest soils and CO_2, CH_4 and N_2O caused by forest fires. The GHGI furthermore includes emissions and removals from changes in the harvested wood product pool using the three product categories, the default half-lives and the stock-change approach used under the Kyoto Protocol. With an outflow larger than inflow, the HWP pool constitutes a net source of emissions equal to 3.2% of the total removals from the category forest land remaining forest land.

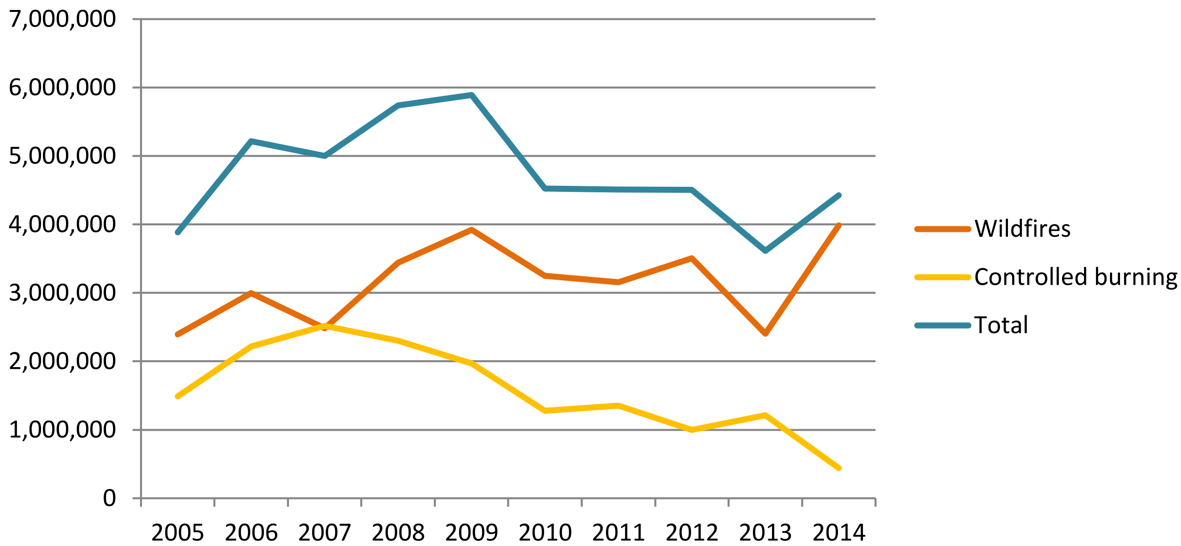
A gain-loss model is applied to the different age classes of the prevailing species for estimating emissions and removals from the managed forest. The model includes gain from increment, loss from harvesting, loss from forest fire and loss from drainage of organic soils. Since calculations are done on the basis of field data on carbon stocks by species and age class, the impacts of CO_2 fertilization, N deposition and age class distribution as well as changes in the water availability and temperature regime are embedded in the carbon stock calculations.

Forest fires: Forest fires together with the annual harvesting constitute the largest annual loss of carbon from managed forests (Zamolodchikov et al, 2013b) and the inter-annual variation is in particular impacted by the inter-annual variation from the impact of forest fires. The reporting of emissions from forest fire on managed land separates controlled burnings from wild fires, with the latter is divided into four categories: ground fires, fires on temporary un-stocked areas, destructive fires and underground fires with different emission factors.

While the majority of forest fires are due to human activities there are also forest fires in unmanaged forests and thus some emissions from forest fires are not included in the GHGI reporting.

Area impacted by forest fire on managed forest land, 2005-2014

Source: Russia's GHGI 2016



Uncertainties

The GHGI includes a quantitative uncertainty analysis for both level and trend. Russia uses tier 1 approach for estimating uncertainties which is made up of uncertainty on the area estimate ±10%, biomass stock ±20%, on conversion factors: for dead wood ±25%, litter ±62%, and soil carbon ±60%. For forest fire the uncertainty is made up of uncertainty on the area estimate and here Russia uses both ground survey with uncertainty of ±3 % and satellite images with uncertainty of ±30 % - with a weighted uncertainty of ±20 % on the area, while the emission factor for N_2O has uncertainty of ±60 % and for CH_4 ±70%[122].

Comparison with independent sources of data and analyses

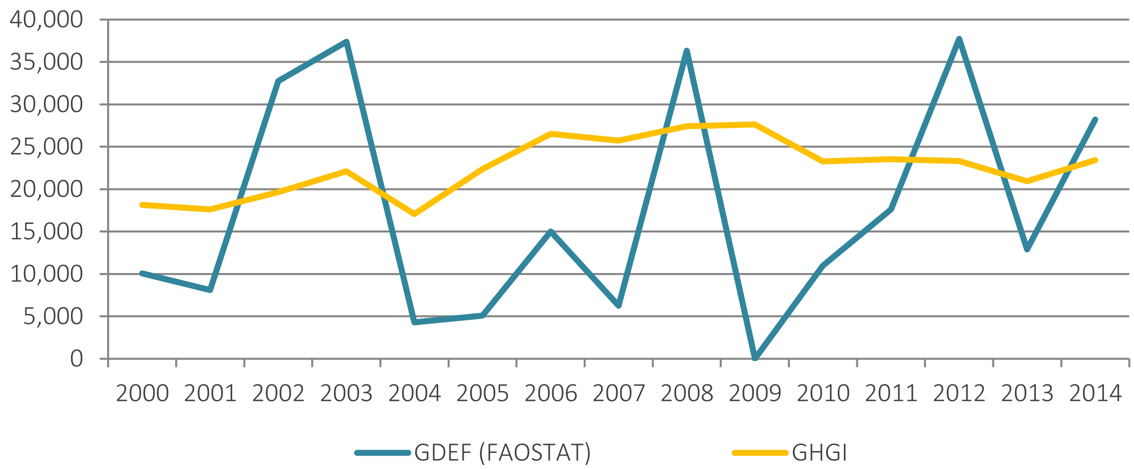
Forest fire: FAOSTAT using Global Fire Emission Database (GFED4)[123] and IPCC Guidelines for National Greenhouse Gas Inventories (tier 1) provides burned area and emissions by country. There are significant differences in emissions from forest fires between the GHGI and the data from GFED4 (see figure below).

[122] From National Inventory Report 2016:
http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/9492.php
[123] http://www.globalfiredata.org/index.html

FAOSTAT/GFED4 has much higher inter-annual variation and on average lower emissions estimates compared to the GHGI[124]. This reflects a methodological difference in how forest fires are detected and taken into account. The GFED4 analysis used satellite thermal imaging and includes forest fires on both managed and unmanaged lands. The FAOSTAT also provides emissions estimates from peat land burning which have not been included here due to an assumption that these occur mainly on grasslands.

For the GHGI activity data from the European part of Russia, emissions are estimated based on statistical data where areas subject to destructive forest fire are identified and allocated to years based on the estimated age of the regeneration. While the success of natural regeneration will depend on biophysical conditions for the site, and thus not be equally successful on all sites, this can add some uncertainty on the year or regeneration, but decrease uncertainty on the area and thus the activity data. With this approach emissions from forest fire tend to average out between years and the GHGI will not have the peaks in emissions seen when using the approach used by the Global Fire Emission Database. For the Asian part the detection is made based on satellite images.

Comparison of non-CO_2 emission from forest fires ('000 tCO_2eq)



Zamolodchikov et al (2013b) compares the statistical approach to estimate forest fire activity data and the use of remote sensing and arrive at similar differences as illustrated in the figure above. The study concludes that the statistical approach only detects about one-third of the fires detected by remote sensing by the Federal Forestry Agency and that about one-third of all fires detected by remote sensing are destructive while others are only low-intensity and medium intensity ground fires. The study concludes that information from the official statistics could therefore be used as a proxy for the area with destructive forest fires. The study focuses on the carbon balance and thus the loss of carbon and not CH_4 and N_20 emissions. Based on forest statistics the study concludes that for the period 1989 to 2009 the average annual carbon loss from clear cuts and destructive forest fires were respectively 330 ± 29 $MtCO_2$/year and 308 ± 33 $MtCO_2$/year. This is significantly larger than the reported forest fire emissions in the GHGI including CO_2, CH_4 and N_20 illustrated in the Figure above. The FRA country report also mentions that national fires statistics do not match well with data produced by remote sensing (Filipchuk et al, 2015).

[124] CO2 emissions from biomass burning provided in the GHGI are not included here in order to make the estimates comparable.

GFW using FAO FRA2015 data estimates a burned forest area of 1 to 2 Mha annually during the period 2005 to 2010 – on average 1.6 Mha/year. This includes forest fires in managed as well as unmanaged forest. This compares well with the area of destructive forest fire reported in the GHGI, which on average for the same period include 1.5 Mha/year, however, FAO FRA data has more inter-annual variation for the area burned.

Forest area and change in forest area: As reported in the table below, there are differences in total forest area reported in the GHGI and Russia's country report the FAO's FRA (2015). The area estimated by Hansen is slightly lower than the forest area reported in the GHGI (but higher than the FRA). One reason for the difference could be different forest definitions used. Hansen estimates forest area using a tree *cover* (10%) definition, while the forest area reported to FRA and in the GHGI use a land *use* definition, which include some temporary unstocked areas as forest land. According to FRA 2015 these lands, which are classified as felled areas, burned-out forests, open forests, failed areas etc. covered 95.7 Mha in 2015 which is more than 10 percent of the total forest area.

Differences in forest cover losses between the data from Hansen and deforestation reported in the GHGI can be reconciled by considering stand-replacing disturbances, as clear-cut and destructive forest fires will be included as a tree cover loss by the Hansen study but in the context of managed forest will be considered as a temporarily unstocked forest area and thus not be included as a deforestation event. GFW also does not distinguish between managed and unmanaged forests which will increase both the forest cover loss and forest cover gain numbers by including natural expansion on unmanaged land as well as destructive forest fires on unmanaged forest land.

Pan et al (2011) has a larger forest area gain and a smaller forest area loss compared to GHGI data and the Hansen study and also larger removal estimate. While the differences to the GHGI data could be partly due to changes in tree cover on unmanaged land, which is not captured by the GHGI. Other differences between the GHGI and Hansen data include the different approaches used to define forest loss and the 50 % tree cover threshold for forest gain used by Hansen.

Source	Estimate
GHGI (forest = minimum 1 ha and 18% tree cover)	Managed forest area (2015) = 685 Mha Unmanaged forest area (2015) = 211 Mha Total forest area (2015) = 897 Mha Forest land to Settlements 10.8 Kha (2015) Cropland to Forest land 4.2 Kha (2015) Unmanaged forest to managed forest 777.8 Kha (2015)
FAO-FRA 2015 report (forest = minimum 0.5 ha and 10% tree cover)	Total forest area (2015) = 815 Mha Including 273 Mha primary, 522 Mha naturally regenerated and 20 Mha planted forest Other wooded land = 75 Mha Other land with tree cover = 20 Mha
Hansen et al (2014) provided by Global Forest Watch (10% tree cover)	Tree cover (2014) = 883 Mha Tree cover gain (2005-2012) = 1.4 Mha/year (using 50% canopy cover) Tree cover loss (2001-2014) = 3.2 Mha/year
Pan (using FAO definition)	Forest area = 846 Mha (as of 2007) Afforestation (2000-2007): 3,1 Mha/year Deforestation (2000-2007): 0,1 Mha/year

Estimated emissions and removals: While forest area data show some differences across different sources, as shown above, GHG estimates differ largely as demonstrated in the next table.

Source	F→NF	F→F	NF→F
GHGI (for the year 2015)	4.6 Mt CO_2eq	-607.7 Mt CO_2eq HWP: 19.4 Mt CO_2 685 Mha managed forest	-4.9 Mt CO_2eq
GHGI annual average for 2006-2015		-646.3 Mt CO_{2eq} HWP: 21.3 Mt CO_2	
FAO FRA (2015)	-302,9 Mt CO2 Forest area 815 Mha in 2015		
Pan et al, 2011 (average 2000-2007)	-1554 Mt CO_2, all forests Forest area 846 Mha		
Houghton (average 2011-2015)		-31 Mt CO_2	-10.3 Mt CO_2 from net land use change

The net removals according to FAO FRA (2015) data for the period from 2010 to 2015 for all forests are only about half of the estimate reported in the GHGI and when looking at longer time period e.g. 2000-2015 the FAO FRA 2015 report suggests the Russian forest was a net source of emissions (31 Mt CO_2/year). There are no clear explanations for these differences.

Houghton uses area data including for land use change, carbon density and harvest data from FAO FRA 2015 and FAOSTAT to estimate emissions and removals and the result is closer to the GHG estimates from FAO FRA 2015 data than the estimates provided in the GHGI.

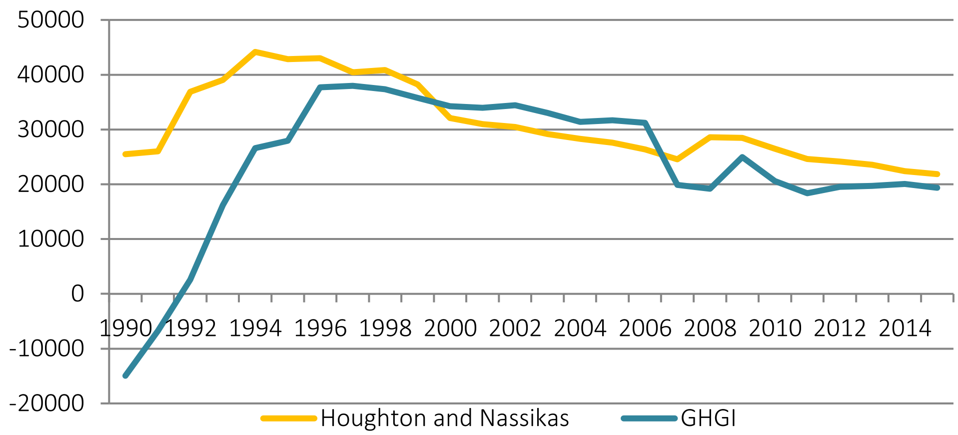
Since the FAO FRA data on land use change is net land use change thus the accumulated effect of forest loss and forest gain, this is not directly comparable with the land use change emissions reported in the GHGI.

Pan et al. 2011, on the other hand, using bottom-up estimates of carbon stocks and fluxes based on national forest inventory data and long-term field observations coupled with statistical or process models, estimates a much larger sink than the GHGI, including a larger relative contribution from both deadwood (27%) and litter (20%) for boreal forest in general. Pan et al. includes all forest, not only managed forests, which makes the area significantly larger than the managed area included in the GHGI.

While some differences can be explained by the differences in forest area included, differences also arise from different methodological approaches and likely also for the activity data and emission factors used. Some studies only focus on carbon and the carbon stock changes which is the case for FAO FRA 2015, Pan et al. and Houghton, while the GHGI also include CH_4 and N_2O emissions from forest fire and drainage and rewetting of forest soils.

A comparison of emissions from HWP for the period 1990 to 2015 is shown in the Figure below. Both time series have a similar trend with decreasing net emissions since 1994-1996. The net emissions during most of the period can be explained by the reduction in harvesting levels and subsequently less domestic use of wood.

Comparison of emissions from HWP ('000 tCO_2)



In addition to the above studies, Zamolodchikov et al. (2011 and 2013a) mentions a number of studies (in Russian) with widely different estimates, however, he also explains how some have made different assumptions. One difference is the estimation of annual increment. Where the current GHGI approach does not assign annual increment to over-mature stands, other studies apply a mean annual increment for the average age class for each species (Moiseey and Filipchuk, 2009). Also different approaches to estimation of emissions from forest fires result in different overall estimates, as well as differences in carbon pools included such as the inclusion of emissions from deadwood decomposition (Moiseey and Alvabina, 2007).

Other studies such as Kurganova et al (2010) estimate that the unmanaged (and therefore unreported) forest areas will also have significant emissions and removals. One example is a large sink of -0.4 Gt CO_2eq annual removals that has been modeled by in the SOM pool of abandoned agricultural land under natural conversion to forest, although no other data has been published to verify this estimate.

What's included in the nationally determined contribution?

As of June 2017, Russia had not ratified the Paris Agreement, and therefore has not submitted an NDC. The Intended Nationally Determined Contribution (INDC) submitted by the Russian Federation (English version) suggests that the contribution will be economy-wide, limit anthropogenic greenhouse gases in Russia to 70-75% of 1990 levels by the year 2030, and include all greenhouse gases reported in the GHGI. To estimate emissions and removals, Russia will use the methodological guidance provided by the IPCC 2006 Guidelines, IPCC 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol and IPCC 2013 Wetlands Supplement.

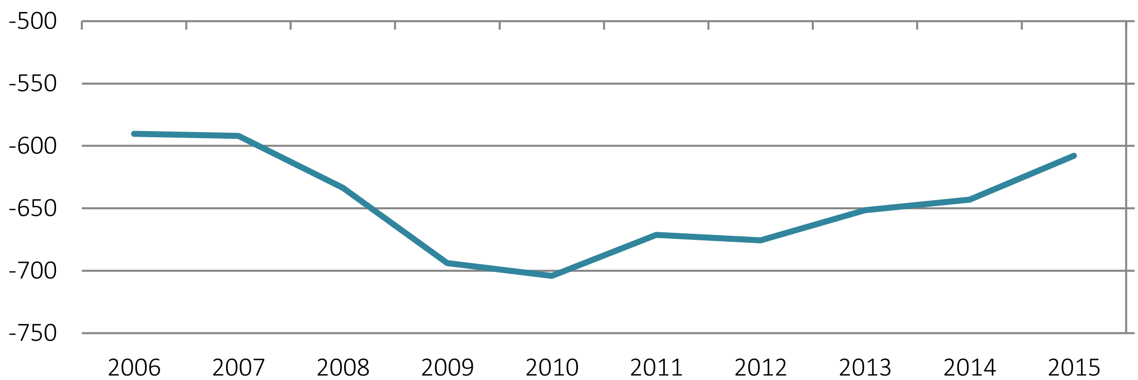
The importance of mitigation in the forest sector is highlighted in the INDC, and the contribution is on the condition that the "maximum possible account of absorbing capacity of forests is included". What this implies is not directly explained in the INDC. However, based on earlier positions by the Russian Federation in the UNFCCC negotiations on this topic, it most likely means that accounting is not limited by a cap. Grassi et al (2017) analyzing the role of forest in meeting mitigation targets in INDCs suggest that the Russian INDC could mean a gross-net accounting approach (i.e. all removals in the target year are counted toward the contribution) and with the scenario for 2030 could imply a mitigation contribution of

0.5 $GtCO_2$ in 2030 equal to 12% of total 1990 emissions from all sectors minus LULUCF or 40% of the total INDC emission reduction. However, this is with a lot of uncertainty related both to projected emissions scenarios and accounting assumptions.

Trends in the reported emissions and removals

The reported GHG fluxes from forest land remaining forest land including emissions from fire show an increasing removals trend from 2006 at -590 $MtCO_2eq$ to 2010 where it peaked at -704 Mt CO_2eq and since decreasing to the latest estimate of -607 $MtCO_2eq$ (see figure below). This fits well with the forecast provided by Zamolodchikov et al. (2013a) which also peak around 2010. However, this study only includes the changes in carbon stocks and not the emissions from forest fire and therefore present higher removal estimates.

Net removal from the category forest land remaining forest land during the period 2006-2015 ($MtCO_2eq$)



The forecast to 2050 of emissions and removals from Russian forests is a significant decrease in removals compared to today's levels. The trend since 1990 in the forest sink is a consequence of the change in harvesting rates since 1990 where annual harvest rates decreased significantly and thus paved the way for the significant increase in net removals since 1990. As a consequence, forest stands are not being rejuvenated and a higher proportion of stands today are over-mature with lower annual removal rates. This results in a forecast to 2050 that shows a significant decrease in net removals under different harvest scenarios including a continuation of the current harvest rates. According to Zamolodchikov et al. (2013a), net removals in 2050 could be only 25% of net removals in 2010.

On the other hand climate change together with CO_2 fertilization are increasing annual increment and have a positive effect on carbon sequestration in the boreal forest. However, climate change is also expected to increase the frequency and severity of pest outbreak and forest fire as well as increase the decomposing rate of dead organic material. The net effect is thus difficult to predict and may vary over time.

The FAO Forestry Sector Outlook Study 2030 also mentions that initial benefits in terms of increased growth rates with climate change in the longer term—after 2030—may have significant negative consequences for boreal forest in terms of, for example, higher forest mortality, increased frequency of forest fire, or increased methane emissions. Particular risks are expected for the southern regions and forest steppe where forest fragmentation and vulnerability is high. All in all, this could switch the boreal carbon forest from sink into source of GHG emissions.

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United States

The United States is the world's second largest GHG emitter, although emissions have been declining since 2007. The country also has the fourth largest forest area in the world—and these forests offset more than 10 percent of US gross emissions, and therefore are an important part of the US inventory. Forest-related sequestration is mainly from increasing carbon stock on forest lands, followed by (in a distant second) sequestration that occurs on settlements (i.e. urban trees), and then land converted to forest land.

The United States, over time, has increased the comprehensiveness of its GHG land use inventory—which now is relatively complete, i.e. reporting on all significant categories, pools and gases. The US has been bringing new "managed" lands into the GHGI over time and now only a portion of Alaska, around 5% of the US total land area, is considered "unmanaged" (compared to 16% five years ago). Some of these new lands identified as "managed" are still not included in the GHGI estimates, and are expected to add a comparatively small source (around 0.25%) to the overall GHGI.

Forest are an important part of the US pathway to decarbonize. The United States' mid-century strategy (to reduce emissions by 80%), suggested that the US land sink could offset up to 45% of economy-wide emissions by 2050. This includes expanding forests an additional 16-20 Mha (on top of an expected 16 Mha by 2020) by mid-century, resulting in an additional 650 $MtCO_2$/year sequestered. Given the importance of the land sink, and despite recent improvements to the GHG inventory, it is critical that the US continue to improve its estimates of GHG fluxes from forests. The US Biennial report illustrates this problem well—currently, the uncertainties are on the order of magnitude of expected economy-wide reductions.[125]

United States reporting under the UNFCCC

As with other developed countries, the United States has submitted six National Communications, two Biennial Reports, and 23 National Inventory Reports (2003–2017). Most recent reporting uses the 2006 IPCC Guidelines and the 2013 IPCC Wetlands Supplement. This analysis is based on the most recent National Inventory Report submission, in April 2017.

What forest fluxes are included in the GHGI?

Data sources: Most information on forest land is provided by the Forest Inventory and Analysis (FIA) program[126], conducted by the US Forest Service. It uses a combination of remotely sensed data with field data collected from grounds plots, a portion of which in each state are sampled every year, with the goal of measuring all plots in a state once every five years in the eastern US and once every ten years in the western US. Because the US forest C inventory is based on repeated national forest inventory (NFI) cycles, or a net C stock change approach, it includes the impact on C stocks from management activities, as well as indirect processes (e.g. CO_2 and N fertilization, temperature regime, water availability), and natural disturbances, such as wildfire, pest outbreaks and storms.

Forests definition and area: The US GHGI defines forest land as the following, i.e. it uses a land use (not cover) definition: "*A land-use category that includes areas at least 120 feet (36.6 meters) wide and at*

[125] 2016 Second Biennial Report of the USA, Section 4 Figure 6.
[126] Hawaii and the interior of Alaska are not currently included in the FIA program

least one acre (0.4 hectare) in size with at least 10% cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated … However, land is not classified as Forest Land if completely surrounded by urban or developed lands, even if the criteria are consistent with the tree area and cover requirements for Forest Land. These areas are classified as Settlements. In addition, Forest Land does not include land that is predominantly under an agricultural land use."

Managed lands: The United States' GHGI includes 936 Mha of land in its "representation of the U.S. land base"[127]. In recent years, the US has increased the total "managed" area from 786 Mha in its 2012 inventory (which considered all of Alaska as unmanaged) to ~890 Mha in the 2015 to 2017 GHGIs, representing a 13% increase in areas considered managed (largely due to the inclusion of portions of interior Alaska). The increase in managed lands added into the inventory (from 2012 to 2015) are mostly grassland (around 70 Mha), followed by wetland and forestland (around 15 Mha each). While this increase in managed land from interior Alaska are now included in the US managed land base, estimates of C stock change from this land are not included in the GHGI due to lack of data. Over time, the US will work to report emissions and removals from all managed lands in the GHGI including those from interior Alaska[128]. And in the meantime, the US does provide a preliminary estimate of fluxes on managed land in Alaska—indicating that forests are a net source of around 46 $MtCO_2eq$/year.

Changes to the definition of managed land over time in the US GHGI

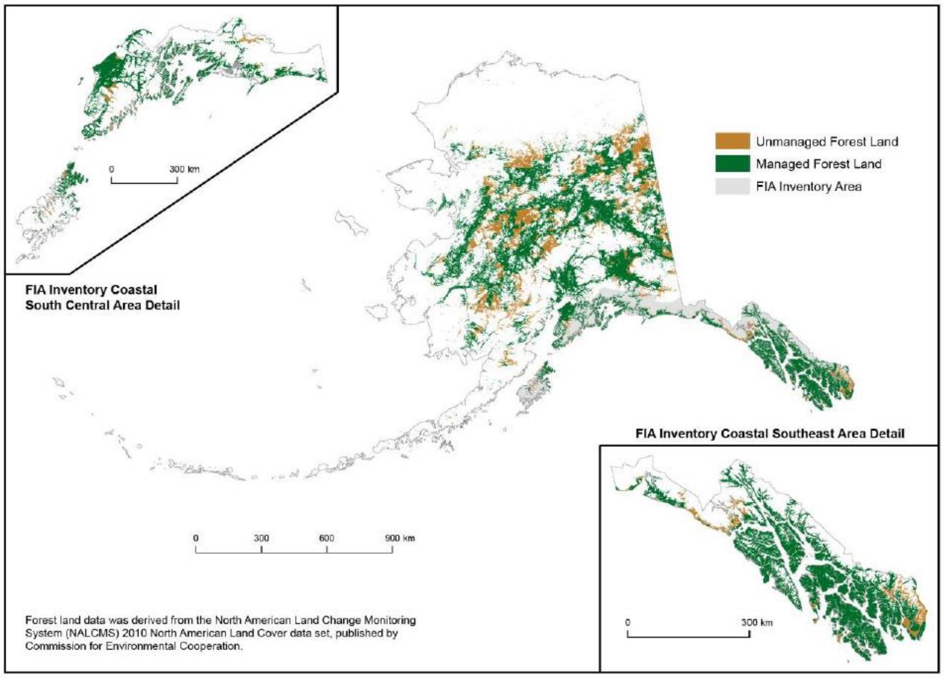
Year of GHGI	*Figures in Mha*		*Comment on land representation and designation of, or changes to, managed lands*
	Managed	Unmanaged	
Up to 2012	786	150	Alaska (in its entirety) and US territories excluded from land representation
2013-2014	867	69	Portions of Alaska added to managed lands in the 2013
2015-2017	890	46	Further refinements to designation of managed lands in Alaska, in particular incorporating lands protected for recreation and with mineral and petroleum extraction

Among its managed lands, 293.5 Mha are identified as forestland. All forestlands with active fire protection are considered managed—therefore, all forests within the "lower 48"[129] are considered managed). 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 there is active management for resource extraction, recreation or to suppress natural disturbances.

Of the 293 Mha of managed forests, the U.S. GHGI includes estimates of emissions and removals on 272 Mha of forested area. C stock changes are not estimated for interior Alaska and portions of Hawaii—which contain the "missing" 19 Mha of forest (around the size of Romania)—even though these are considered "managed". This is a current gap in the GHGI that results in discrepancies between the land identified as managed compared to lands where fluxes are estimated and reported.

[127] The US GHGI currently does not include US territories. It states planned improvements will include these lands in future reports, which comprise around 1 Mha, or 0.1% of the total US land area.
[128] See "Planned Improvements" in Forest Land Remaining Forest Land and Grassland Remaining Grassland in the 2017 GHGI.
[129] The "lower 48" refer to the contiguous 48 states on the continent (i.e. excluding Alaska and Hawaii).

Managed and unmanaged forest in Alaska



Another gap in the US GHGI is that agroforestry systems that meet the definition of forest land are also not included in the GHGI, although C stock changes in such systems are not likely to be significant[130].

Unmanaged lands: As with Canada and Russia, and consistent with IPCC Guidance, C stock changes on unmanaged land are not reported in the GHGI. Around 3% (46 Mha) of the total US land base is considered unmanaged. All lands considered "unmanaged" are located in Alaska and are considered inaccessible to society due to the remoteness of the location. Among lands considered unmanaged are 8.6 Mha of forest land. The main fluxes on unmanaged land come from: growth (uptake likely driven by climate change and CO_2 and N fertilization); emissions from natural disturbances such as wildfire, pest and disease, drought and floods; and the impacts of permafrost thaw. The US GHGI includes a preliminary estimate of forest fluxes in all of Alaska's managed lands, suggesting that between 2000-2009 unmanaged forests were a net source (emission) of around 45 $MtCO_2eq$/year. This figure is around 16% of the net emissions from forests in 2015, but less than 1% of the US total net emissions (from all sectors). Hawaii's forests are smaller and are not expected to influence the overall C budget (but data on these forests are expected to be added once available).

Category/Activity coverage: The FIA is the main database for forest-related fluxes. It uses remotely-sensed data (aerial photographs and satellite imagery) combined with field data. Activity data for forests in the "lower 48" (plus non-federal lands in Hawaii) use Approach 2, i.e. spatially explicit representation are not provided for all parcels of land although all land use and land-use conversions are tracked explicitly at the survey locations. Land areas in Alaska and federal lands in Hawaii are tracked using spatially explicit data (Approach 3).

[130] According to the US EPA, reliable data is not available at this time for agroforestry systems, but research efforts are underway and it will be several years before data is available for use in the Inventory. Furthermore, such systems tend to be a source or sink in the case of area decreases or increases respectively, which does not appear to be the case in US.

A full land-use conversion matrix is developed[131], using statistics from other datasets to gap-fill where the FIA does not provide data (e.g. the types of lands when F > NF, or NF > F), which requires adjustments due to discrepancies (from different criteria for classifying forest land and different sampling designs) between the datasets.

	Forest-related category coverage		
	F > NF	F > F	NF > F
NIR (2017 draft)	Estimates provided for: F > CL, F > GL, F > S	F > F is the largest LULUCF flux reported in the US GHGI.	Prior to the 2016 GHGI, land converted to forestland was included in the F > F category. This is now estimated separately.

The following are estimates of C stock change for all forest-related subcategories from the 2017 GHGI, which for the first time includes estimates for the subcategory "forests converted to settlements".

All figures in MtCO₂eq	1990	2005	2011	2012	2013	2014	2015
F > F	-698.5	-665.4	-670.7	-667.7	-671.6	-670.0	-669.9
L > F	-92.0	-81.4	-75.8	-75.2	-75.2	-75.2	-75.2
F > CL	17.8	7.4	3.2	3.6	3.6	3.6	3.6
F > GL	26.1	32.0	32.5	32.3	32.3	32.3	32.3
F > S	29.0	42.3	46.7	44.8	44.8	44.8	44.8
Net forest flux	**-717.6**	**-665.1**	**-664.1**	**-662.2**	**-666.1**	**-664.5**	**-664.4**

*F > F includes sequestration from harvested wood products, but does not include C stock changes from drained organic soils

Pools: All significant forest-related pools are estimated in the 2017 GHGI. For all forest-related categories, above and below ground biomass, deadwood and litter are estimated—**this is a significant change from past inventories where changes in these pools were not included for "land converted to forest land" and "forest land converted to other land"**. Soil C stock changes are estimated per the chart below:

Category	GHG fluxes from soil estimated in GHGI
Forest > Forest	Changes in C stock from mineral and organic soils; application of synthetic fertilizer to forest soils and the draining of organic soils
Land > Forest	Changes in C stock from mineral soils
Forest > Cropland	Changes in organic C stocks in mineral and organic soils due to land use and management
Forest > Grassland	Changes in organic C stocks in mineral and organic soils due to land use and management
Forest > Settlement	Changes in organic C stocks in mineral and organic soils due to land use and management

The harvested wood pool is included in the GHGI, using the production approach[132] and includes harvested wood products (HWP) in use and HWP in solid waste disposal sites (much of which is discarded in such sites versus incineration). HWPs comprise around 5% of the carbon sequestration from forests.

Environmental impacts: The collection of field data on a network of ground plots were historically conducted periodically, with all plots in a state being measured at a frequency of every five to 14 years. A

[131] This is not true of earlier versions of the US GHGI, which stated that while the US had data on the magnitude of changes for NF→F, it did not have reliable and comprehensive estimates of CO_2 or N_2O fluxes across a full matrix of land use and land-use changes to report these fluxes separately in subcategories, and for this reason included the estimates within F→F (including transfers to the harvested wood pool). It also included under F→F C stock changes in living biomass for F→NF (e.g. conversion to croplands or other lands).

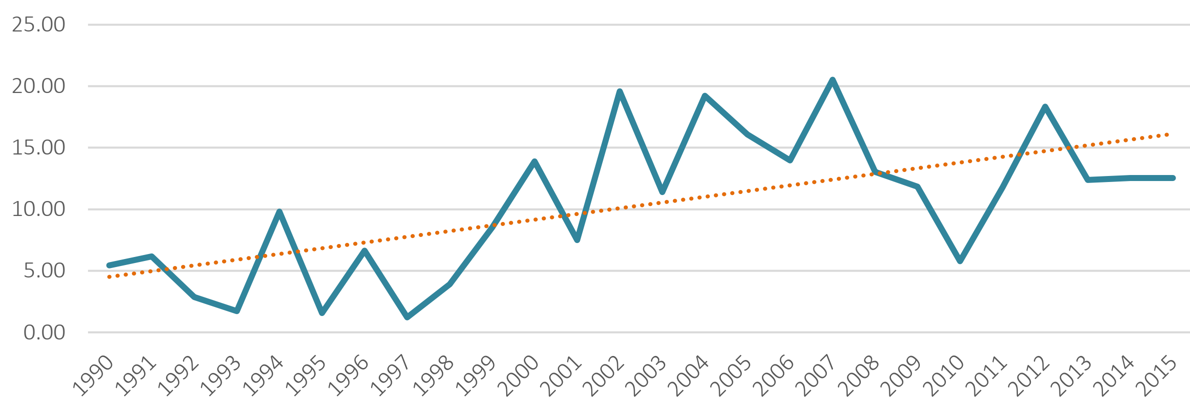
[132] The production approach estimates HWP based on wood *produced* in the country, including exports (as opposed to the stock-change or atmospheric flow approaches which are based on products consumed). The US GHGI (Annex 3.13) provides estimates for these other methods and suggests they would yield *larger* estimates of removals than the production approach.

new national plot design and annual sampling design (with a portion of plots sampled each year, with the goal of measuring all plots once every five years in the eastern US and once every ten years in the western US) was introduced by FIA about ten years ago, although only recently have all states been brought into the new system.

The GHGI largely uses a stock-difference approach (several smaller sources, e.g. estimating fluxes from drained organic soils, may use other methods of estimation) and **therefore C stock changes associated with environmental impacts and disturbances (e.g. CO_2 and N fertilization from atmospheric deposition, forest fire, pest outbreaks, etc.) are implicitly included in the estimates** (and not separately itemized).

Gases: Non-CO_2 emissions from forest-related categories that are estimated in the GHGI include CH_4 and N_2O from forest fires and drained organic soils, and N_2O from fertilizer application to soil in forestland remaining forestland. The majority of non-CO_2 emissions are CH_4 and N_2O from forest fires[133], which are estimated using a combination of US-specific data on areas burned, fuel available for combustion (from C density estimates from FIA data for each state), and IPCC default combustion and emission factors. In 2015, fires were responsible for 12.1 $MtCO_2eq$ in non-CO_2 gases, which offset about 2% of the forest sink. By comparison, N_2O from fertilizer application to forest soils has historically been very small, approximately 0.5 $MtCO_2eq$. Emissions from forest fires has high inter-annual variability and has been increasing since the 1990s, as illustrated in the Figure below.

Non-CO_2 emissions from forest fires (in $MtCO_2eq$ with linear trendline)



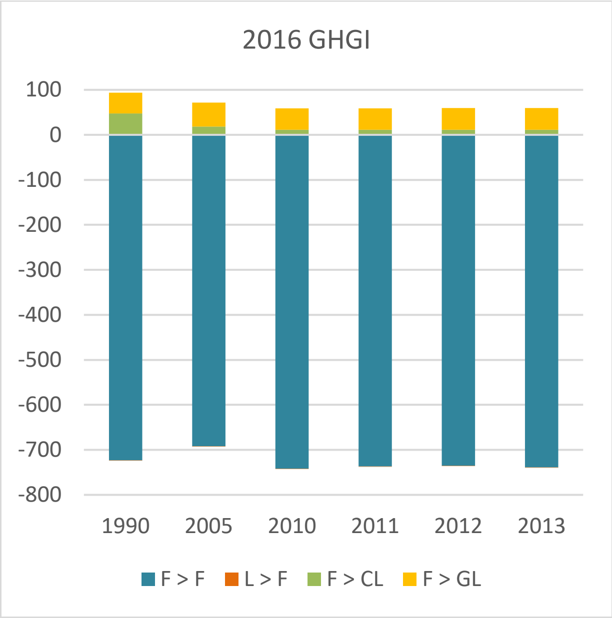
Recent changes in methodologies: The 2017 GHGI includes several changes in the forest and land use sector that demonstrate how the US continues to improve its inventory. In particular, the 2017 US GHGI is more complete than previous reports, adding the new subcategory "forests converted to settlements" and new pool coverage, including biomass and dead organic matter for "forests converted to grasslands" and "forest converted to croplands". In addition to these new additions, other improvements or changes include:

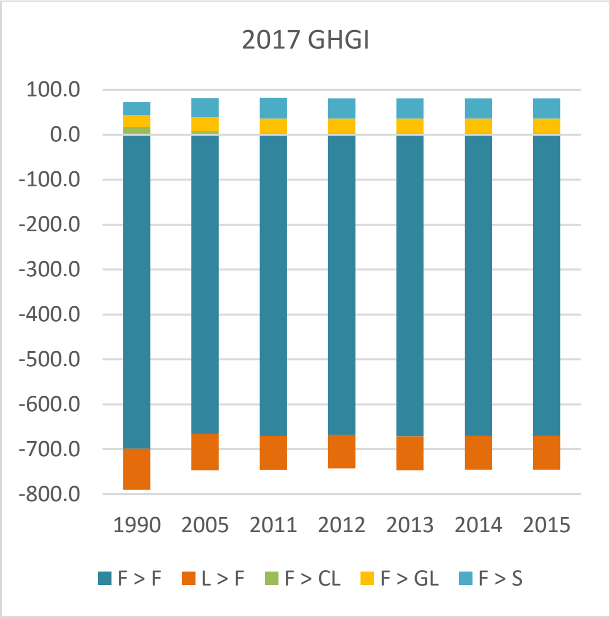
- Reporting F → F and L → F separately; in previous GHGI reports these were merged into F > F;
- A new approach to estimating forest soil carbon (the largest C stock in the US), including the separation of flux estimates from mineral vs. organic soil;
- Slight changes to designation of managed lands in south central and southeastern coastal Alaska (reducing the percentage of managed forest in Alaska by ~5%);

[133] CO_2 emissions from fire are implicitly included due to the use of the stock-change approach. However, the US GHGI provides estimates of C stock change specifically from forest fires. From 2001-2015, CO_2 emissions from forest fires ranged from 91 to 144 $MtCO_2eq$/year.

- Emissions from drained organic soil for forests are reported for the first time in the 2017 GHGI (using the 2013 Wetlands Supplement to the 2006 IPCC GL).

These changes are illustrated in the Figures below.





Reporting on Uncertainties

The US reports on uncertainties for each forest transition. Sample and model-based error are combined using simple error propagation methods provided by the IPCC (2006 GL) or, in some instances, applying a Monte Carlo analysis (e.g. for soil C stock changes). The table below summarizes the most significant transitions and their uncertainties for the US GHGI:

	Uncertainty range	
	Lower bound	Upper bound
FL > FL	-37.5%	37.5%
L > FL	-10%	11%
FL > CL	-11%	11%
FL > GL	-19%	19%
FL > S	-4%	4%
Non-CO2	-60-63%	157-161%

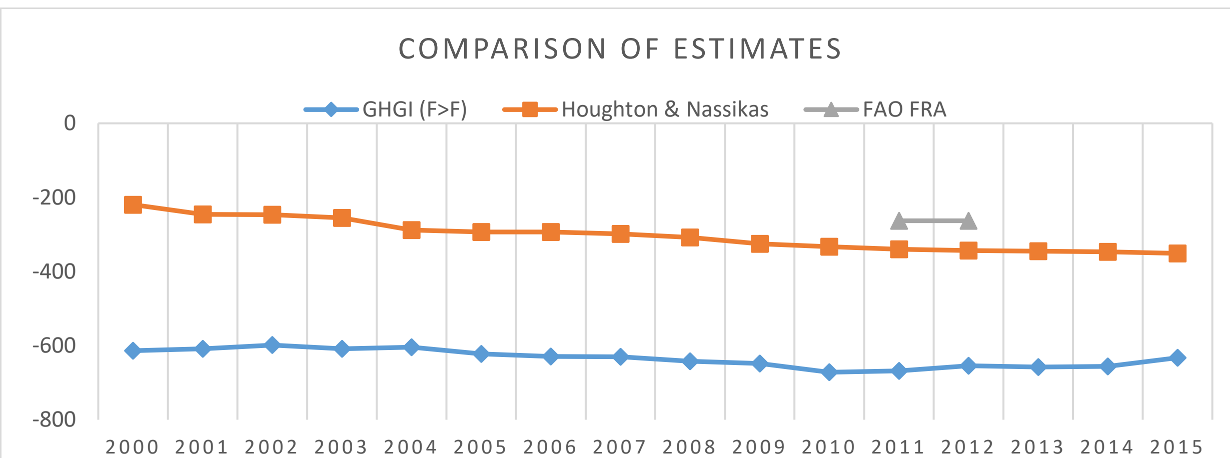
Comparison of national reporting to independent studies

There are a number of studies that estimate US forest fluxes. A table comparing US GHGI estimates with several of these estimates is provided below—including FRA and Houghton estimates—which appear to vary considerably. As with other case studies, this section attempts to offer potential explanations for the differences.

Comparison of various estimates of forest fluxes in the United States

	All figures in $MtCO_2eq$			Coverage*	
Source	F→NF	NF→F	F→F	Pools	Gases
Estimates for the period 2011-2015 (annual average)					
US GHGI (2017) (2011-2015 average)	81	-75	-670 (-77 HWPs, 13 fire)	AGB, BGB, DW, L, Soil, HWP	CO_2, N_2O, CH_4
	-664				
FAO FRA (2015)[134] (2007-2012 average)	0	-97	-166	AGB, BGB, DW, L, Soil	CO_2
	-263				
Houghton (2011-2015 average)	-88 (based on net forest change)		-257 (includes HWP)	AGB, BGB, DW, L, Soil, HWP	CO_2, N_2O, CH_4
	-345				

**Parentheses indicates only partial coverage (i.e. may be missing for some categories)*



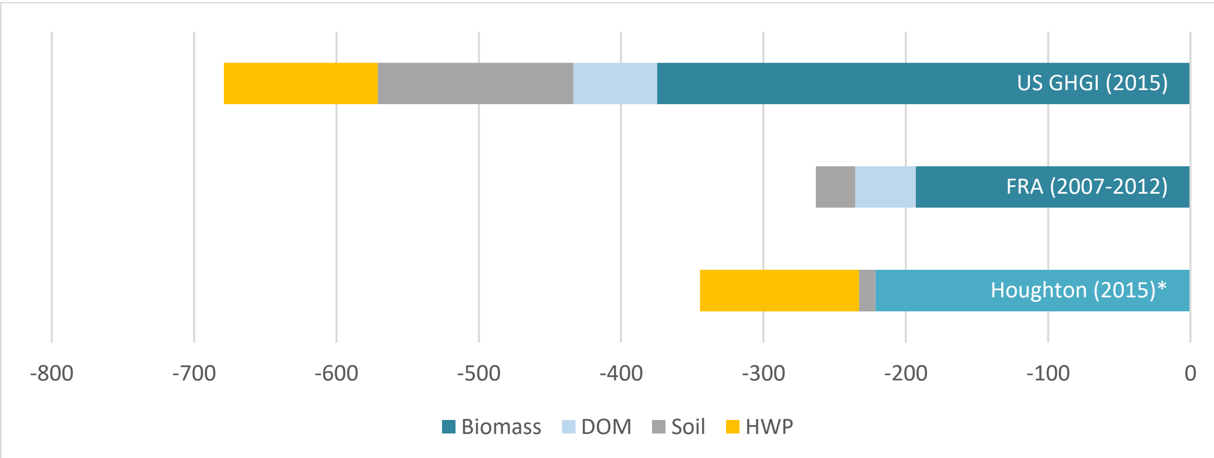
Houghton, using the bookkeeping method, calculate a considerably smaller sink from US forests than the national GHGI. The figure below, which separates the four estimates above by pools (biomass, dead organic matter, soil and harvested wood products), suggests that the difference is largely accounted for by significantly lower estimates of removals from biomass, DOM and soil and less so from HWPs. Most of the difference *may* be attributed to the fact that Houghton assumes C stock changes in forests remaining forests are constant except for areas of harvest or fire. By contrast, the US GHGI estimates all C stock changes in forests located in managed lands. The difference relates to the way in which Houghton, compared to IPCC methods for GHGIs, assumes "what is anthropongenic"[135]. While Houghton's bookkeeping method assumes the only anthropogenic changes in F→F are due to harvesting (and, for the

[134] Figures derived from the United States' country report to the FAO Forest Resources Assessment (Federici et al, 2015; some data unpublished); note that the FRA figures provided by the United States in the 2015 country report are for 2012, and the 2020 report for 2007.

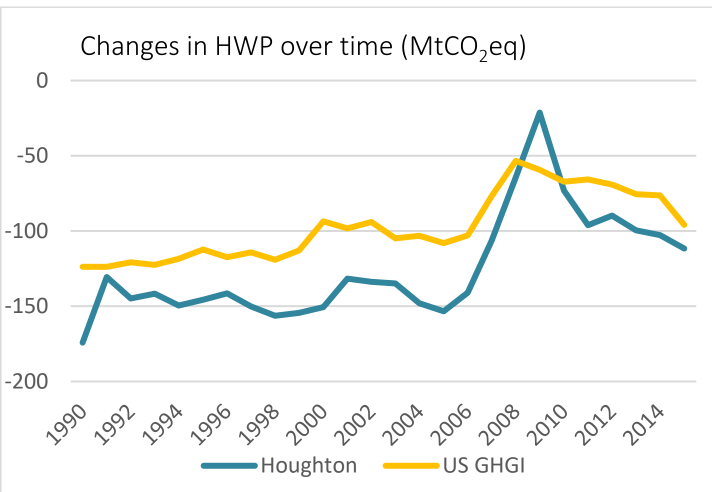
[135] See *GHG fluxes from forests: An Assessment of national GHG estimates and independent research in the context of the Paris Agreement*, Sections 3.1 and 3.2,

US, fire management), therefore it does not include environmental impacts such as CO_2 fertilization and N deposition that occur across the entire forest land in the US. By contrast, the national GHGI estimates all C stock changes in forests on managed lands and considers them anthropogenic (per IPCC guidance). It uses C stock measurements from plot level data from repeated NFIs to measure such changes across all managed forest land.

Comparison of C stock changes by pools ($MtCO_2eq$)



*Houghton combines biomass and DOM



Houghton estimates of HWP removals approximates relatively well US GHGI data. Small differences may be due, in part, to the assumptions on decay rates, as shown in the table below. Pan uses the same underlying methodology (Skog, 2008[1]) as the US GHGI, explaining why the estimates are nearly identical for the time period.

Half-life (in years)	Solid wood	Paper products
US GHGI, Pan	Housing: 78-84 Other: 38	2.54
Houghton	69.3	6.9

US country report to the FRA (2015) suggests significantly different estimates of forest fluxes compared to the GHGI. The GHGI uses a different method to calculate forest flux estimates than those derived from the FRA (using the method from Federici et al, 2015). It is also worth noting that the data in the 2015 US country report to the FRA used older methods from calculations performed in 2013-2014 and are therefore more comparable to the 2013 GHGI than the 2017 GHGI, where methods have been updated (some of these updates are noted in the section above). The table below illustrates where the largest discrepancies can be found. One may expect the FRA to estimate higher C stock removals—given it includes all forest area (not just managed land), but the opposite appears to be the case.

Comparison of GHGI (2017) to derived estimates of forest fluxes from FRA (2015)

Note: The FRA report suggests there is no deforestation (NF→F), whereas the GHGI includes emissions in this category.

	F→F		NF→F	
	GHGI	FRA	GHGI	FRA
Biomass	-374.6	-136.8	-31.9	-56.1
DOM	-58.9	-20.0	-43.1	-22.6
SOM	-137.6	-9.4	-0.2	-18.4
Total	**-571.1**	**-166.2**	**-75.2**	**-97.0**
HWP	-95.9	N/A	N/A	N/A

Comparing estimates of forest area, gain and loss

One reason for differences in overall net forest flux estimates is differences in how forest cover and forest cover change is estimated, and then translated into emission/removal estimates. The table below compares data from the US GHGI (2017), US country report to the FRA (2015) and the Hansen data (from Global Forest Watch) due to its popularity as a globally consistent data source for forest cover and change.

Source	Forest area	Forest area loss	Forest area gain
2017 US GHGI*	272.1 Mha (2015)	+359,250 ha/yr (2011-2015 average net forest area change) +496,500 ha/yr (2005-2011 average net forest area change)	
2015 US FRA**	310.1 Mha (2012)	+275,000 ha/yr (2007-2012 average)	
Hansen (10% canopy cover)	315 Mha (2000) 302.5 Mha (2012, implied)	-2.39 Mha/yr (2001-2012)	1.26 Mha/yr (2001-2012)

* Forest areas included in the GHGI, i.e. "managed" forest area minus interior Alaska (19.9 Mha), Hawaii (1.5M ha) and US territories (0.5 Mha); unmanaged forest area is 8.6 Mha.
**Forest area change calculated by subtracting forest area reported in 2010 with that reported in 2015 (for the year 2012) and dividing by 2; forest expansion reported for 2010 is 275,000. FAO FRA data used by Houghton.

Forest area: The difference between the GHGI and the FRA report is partly related to coverage. While the FRA reports on all forest land, the GHGI reports only on managed lands and does not yet include interior Alaska and Hawaii (and US territories). Total managed plus unmanaged forest land is 302 Mha, compared to the 310 Mha reported in the FRA. There are also differing definitions of woodlands (FRA reports 21 Mha compared to the GHGI estimates of 12.3 Mha). The US is currently working towards reconciling these differences.

Forest area change: There are more significant differences in the estimated forest area change. The US country report to the FRA and NIR use the same underlying data, but there may be differences in how forests are classified and methods to calculate and classify net forest area change[136]. For instance, the GHGI follows IPCC guidance to keep land in a conversion category for a 20-year period. We were unable to reconcile the data or explain why there are differences in area change. While Hansen tree cover is comparable to FRA data, both loss and gain are much higher, likely because Hansen does not yet separate harvesting (considered F→F in the GHGI) from deforestation (i.e. land use change), counting both as "tree cover loss" (i.e. employing a land cover versus land use definition). Similarly, the large tree cover gain is likely capturing regrowth on forest plantations.

[136] The FRA is calculated using data from the Resources Planning Act (comparing data from 2010 and 2015), while the NIR uses annual data from the Forest Inventory and Analysis (FIA), National Resources Inventory (NRI) and National Land Cover Dataset (NLCD) to create a time series from 1990 to the current inventory year (in this case 2015).

The United States' Nationally Determined Contribution

The US NDC states that all GHGs included in the 2014 Inventory of United States Greenhouse Gas Emissions and Sinks are included in the NDC. It uses a base year of 2005 and has a single year target, 2025, i.e. it intends to reduce emissions 26 to 28% below its 2005 level in 2025. Land use is included as part of the economy-wide target. The United States provided one of the clearest explanations of how land use would be accounted, as stated below:

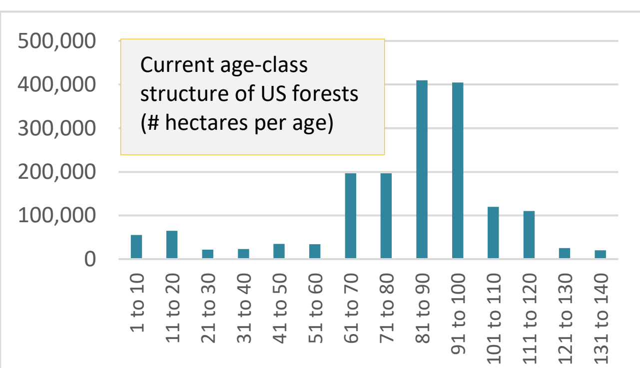
> *"...to account for the land sector **using a net-net approach**; and to use **a "production approach" to account for harvested wood products** consistent with IPCC guidance. The United States may also **exclude emissions from natural disturbances, consistent with available IPCC guidance**. There are material data collection and methodological challenges to estimating emissions and removals in the land sector. Consistent with IPCC Good Practice, the United States has continued to improve its land sector greenhouse gas reporting, which involves updating its methodologies. The base year and target for the U.S. INDC were established on the basis of the methodologies used for the land sector in the 2014 Inventory of United States Greenhouse Gas Emissions and Sinks and the United States 2014 Biennial Report*."

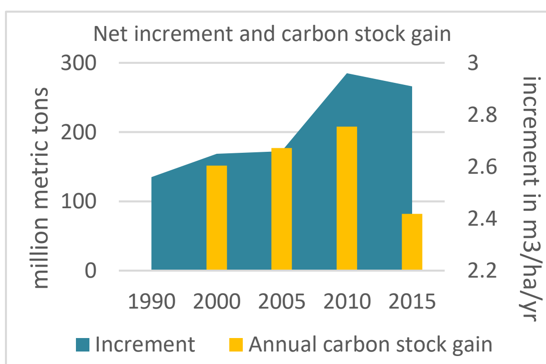
This statement seems to indicate that the United States "target" covers all forest-related fluxes included in its 2014 GHG inventory. It is unclear if the US would estimate achievement of its NDC using 2014 methods or update the calculations, given it has made improvements in both methods and scope for estimating forest fluxes (as noted above).

Trends in GHG forest fluxes in the United States

Over the past decades, forest land area in the U.S. has been increasing, largely due to the conversion of abandoned croplands to forest. The major influences to the net C flux from forest land are management activities (e.g. intensified management leading to increased rate of growth and density of biomass stored in forests) and the ongoing impacts of previous land-use conversions. Therefore, US forests have been a net sink sequestering around 10% of total gross national emissions.

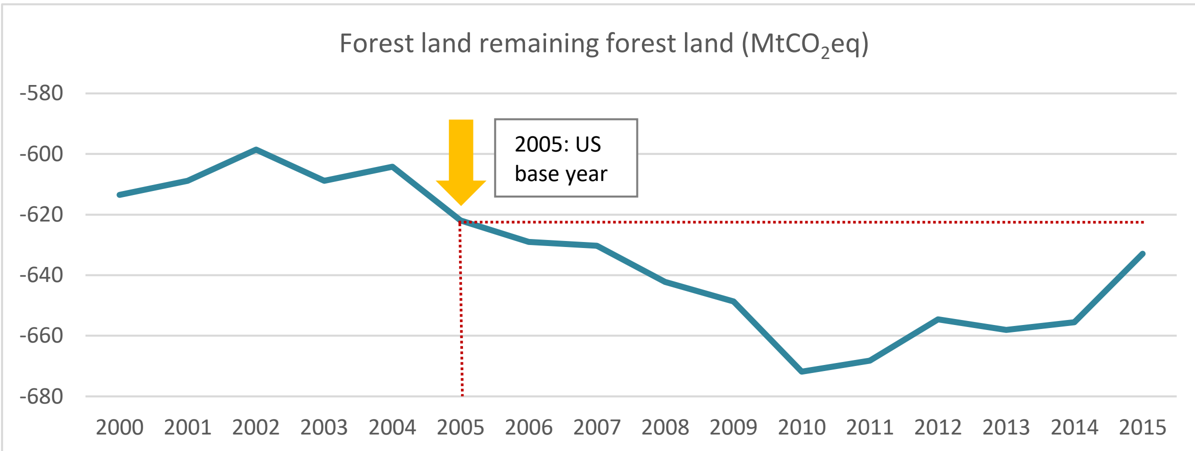
There are currently differing views on whether this sink will persist. Projections by the US forest service and independent studies (Wear and Coulston, 2015; Funk and Saunders, 2014)[137] suggest that the sink is threatened by deforestation, increasing demand for bioenergy, and aging forests (largely harvested around 100 years ago, see images below). In addition, due to climatic changes, drought, pest infestations and forest fires (emitting around twice as much non-CO_2 gases compared to 1990) are increasing. These factors contribute to what seems like a peaking of the forest sink anywhere from 2010 to 2030.





[137] Wear and Coulston (2015) estimate that the US forest carbon sink will decrease from its current -173 TgC/yr to 112 TgC/yr over the next 25 years.

However, projections from ecosystem process models that reflect the age class structure, but also several indirect climate impacts (e.g. CO_2 fertilization and N deposition), indicate that the forest carbon sink may persist for many more decades before saturating. The harvested wood product pool has been slowly increasing removals since 2008 and there is also a slow increase in conversion of abandoned cropland to forest land. Models that also include carbon price signals and incentives for land owners show a potentially increasing sink (McGlynn et al, 2016).



it is therefore unclear whether the US net-net approach is more or less conservative compared to a BAU reference level. In other words, it is unclear whether a BAU calculation of the forest sink for 2025 would be more or less than the 2005 sink (the US base year). In 2000 the forest sink was 613 $MtCO_2eq$, in 2010 it peaked at around 670 $MtCO_2eq$ and in 2015 it had declined to 633 $MtCO_2eq$.

Sources

Funk and Saunders (2014). Rocky Mountain Forests at Risk: Confronting Climate-driven Impacts from Insects, Wildfires, Heat and Drought. Union of Concerned Scientists and the Rocky Mountain Climate Organization.

McGlynn et al (2016). Building Carbon in America's Forest, Farms and Grasslands: Foundations for a Policy Roadmap. Forest Trends.

Wear and Coulston (2015). From Sink to Source: Regional variation in US forest carbon futures. *Nature*, *Scientific Reports* 5, Article number: 16518. doi:10.1038/srep16518

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.
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.
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.
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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.
	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: Additional information

(a) Brazil

Table 1: Net GHG emissions from classified deforestation ($MtCO_2eq$)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		2003-2005 (3 years)		2006-2010 (5 years)	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	8,055	1,007	5,114	1,705	3,727	745
Cerrado	1,605	201	729	243	1,215	243
Caatinga	221	28	108	36	180	36
Atlantic	908	113	789	263	1,314	263
Pampa	18	2	43	14	71	14
Pantanal	169	21	51	17	85	17
Total	**10,975**	**1,372**	**6,833**	**2,278**	**6,592**	**1,318**
Average annual	1,619				1,318	

Table 2: Net GHG emissions from all deforestation [classified + unclassified] ($MtCO_2eq$)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		2003-2005 (3 years)		2006-2010 (5 years)	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	8,054.8	1,006.8	6,889.7	2,296.6	5,451.7	1,090.3
Cerrado	1,607.2	200.9	729.9	243.3	1,216.5	243.3
Caatinga	222.8	27.8	125.7	41.9	209.5	41.9
Atlantic	907.6	113.5	788.7	262.9	1,314.4	262.9
Pampa	18.3	2.3	42.8	14.3	144.0	28.8
Pantanal	168.9	21.1	50.8	16.9	84.7	16.9
Total	**10,979.6**	**1,372.4**	**8,627.6**	**2,875.9**	**8,420.8**	**1,684.2**
Average annual	1,782.5				1,684.2	

Table 3: Net GHG removals from classified afforestation ($MtCO_2eq$)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		2003-2005 (3 years)		2006-2010 (5 years)	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	-30.1	-3.8	31.8	10.6	-8.5	-1.7
Cerrado	-32.6	-4.1	-73.9	-24.6	-123.2	-24.6
Caatinga	-26.3	-3.3	-71.0	-23.7	-118.3	-23.7
Atlantic	-41.3	-5.2	-125.5	-41.8	-209.2	-41.8
Pampa	-3.1	-0.4	-20.0	-6.7	-33.4	-6.7
Pantanal	-0.6	-0.1	-0.6	-0.2	-1.0	-0.2
Total	**-134.1**	**-16.8**	**-259.3**	**-86.4**	**-493.5**	**-98.7**
Average annual	-35.8				-98.7	

Table 4: Net GHG removals from classified managed forest land ($MtCO_2eq$)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		2003-2005 (3 years)		2006-2010 (5 years)	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	-1,025.3	-128.2	-554.0	-184.7	-1,424.3	-284.9
Cerrado	-49.2	-6.2	-32.3	-10.8	-53.8	-10.8
Caatinga	-6.7	-0.8	-10.8	-3.6	-18.0	-3.6
Atlantic	-14.8	-1.9	56.3	18.8	93.8	18.8
Pampa	0.1	0.0	2.1	0.7	0.0	0.0
Pantanal	-0.7	-0.1	-1.6	-0.5	0.0	0.0
Total	**-1,096.7**	**-137.1**	**-540.3**	**-180.1**	**-1,402.2**	**-280.4**
Average annual	-148.8				-280.4	

Table 5: Deforestation classified area (ha)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		2003-2005 (3 years)		2006-2010 (5 years)	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	15,571,843	1,946,480	9,823,519	3,274,506	7,592,906	1,518,581
Cerrado	8,393,395	1,049,174	3,777,143	1,259,048	6,295,239	1,259,048
Caatinga	3,438,110	429,764	1,461,191	487,064	2,435,318	487,064
Atlantic	2,318,450	289,806	1,920,414	640,138	3,200,690	640,138
Pampa	77,506	9,688	194,733	64,911	324,556	64,911
Pantanal	688,514	86,064	212,762	70,921	354,604	70,921
Total	**30,487,818**	**3,810,977**	**17,389,763**	**5,796,588**	**20,203,312**	**4,040,662**
Average annual	4,352,507				4,040,662	

Table 6: Deforestation unclassified area (ha)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		2003-2005 (3 years)		2006-2010 (5 years)	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	0	0	3,411,108	1,137,036	3,514,970	702,994
Cerrado	13,570	1,696	5,089	1,696	8,481	1,696
Caatinga	31,313	3,914	235,169	78,390	391,948	78,390
Atlantic	0	0	0	0	0	0
Pampa	0	0	0	0	329,869	65,974
Pantanal	0	0	0	0	0	0
Total	**44,883**	**5,610**	**3,651,365**	**1,217,122**	**4,245,268**	**849,054**
Average annual	336,023				849,054	

Table 7: deforestation all [classified + unclassified] area (ha)

Source: GHGI from Brazil's 3rd National Communication

	1994-2002 (8 years)		*2003-2005 (3 years)*		*2006-2010 (5 years)*	
Forest Biome	Total	Annual	Total	Annual	Total	Annual
Amazon	15,571,843.2	1,946,480.4	13,234,627.0	4,411,542.3	11,107,876.0	2,221,575.2
Cerrado	8,406,964.3	1,050,870.5	3,782,231.9	1,260,744.0	6,303,719.8	1,260,744.0
Caatinga	3,469,423.3	433,677.9	1,696,359.9	565,453.3	2,827,266.5	565,453.3
Atlantic	2,318,450.3	289,806.3	1,920,413.7	640,137.9	3,200,689.5	640,137.9
Pampa	77,505.8	9,688.2	194,733.5	64,911.2	654,425.3	130,885.1
Pantanal	688,513.9	86,064.2	212,762.2	70,920.7	354,603.7	70,920.7
Total	**30,532,700.8**	**3,816,587.6**	**21,041,128.2**	**7,013,709.4**	**24,448,580.7**	**4,889,716.1**
Average annual	4,688,529.9				4,889,716.1	

Table 8: Data on forest area (ha) for each biome, and net area change between following years

Source: Mapbiomas

Year		2009	2010	2011	2012	2013	2014	2015
Amazon	Forest area	346,747,449	347,909,662	348,446,445	347,329,808	345,275,053	343,981,130	344,004,805
	Net area change	1,136,914	1,162,213	536,783	-1,116,637	-2,054,755	-1,293,923	23,676
Cerrado	Forest area	46,785,411	46,503,062	45,826,677	43,691,127	42,910,881	42,090,806	42,090,721
	Net area change	1,032,125	-282,349	-676,386	-2,135,549	-780,246	-820,075	-86
Caatinga	Forest area	27,057,203	27,062,229	24,828,103	18,540,738	20,722,266	20,037,465	20,020,475
	Net area change	646,939	5,026	-2,234,126	-6,287,365	2,181,528	-684,801	-16,991
Atlantic	Forest area	32,374,705	33,324,547	34,609,431	34,251,161	33,792,051	34,170,618	34,163,537
	Net area change	1,096,132	949,842	1,284,884	-358,270	-459,109	378,566	-7,081
Pampa	Forest area	1,919,944	2,049,039	2,144,952	2,077,023	2,103,200	2,144,835	2,141,573
	Net area change	116,971	129,095	95,913	-67,929	26,176	41,635	-3,262
Pantanal	Forest area	5,250,737	5,297,638	5,348,264	5,181,998	5,159,202	5,234,627	5,240,155
	Net area change	135,478	46,901	50,626	-166,266	-22,797	75,425	5,528
Total Brazil	Forest area	460,135,450	462,146,178	461,203,872	451,071,856	449,962,653	447,659,482	447,661,265
	Net area change	4,164,558	2,010,728	-942,306	-10,132,016	-1,109,203	-2,303,171	1,783

Table 9: Time series of GHG emissions and removals, various sources

Table 9 - GHG emissions and removals time series

	Houghton				FRA				GHGI				SEEG			
	NF→F	F→F	F→NF	TOT	NF→F	F→F	F→NF	TOT	NF→F	F→F	F→NF	TOT	NF→F	F→F	F→NF	TOT
	Mt CO_2eq yr^{-1}															
1990	-3.9	56.3	573.0	625.4	-14.0	-460.3	1,872.9	1,398.5				0.0	-22.2	-203.8	1,094.9	868.9
1991	-3.7	56.3	655.0	707.6	-14.1	-458.2	1,874.7	1,402.5				0.0	-22.2	-208.2	949.5	719.2
1992	0.9	57.4	728.7	787.1	-14.1	-456.0	1,876.5	1,406.4				0.0	-22.2	-211.0	1,109.5	876.3
1993	-1.3	58.1	781.9	838.7	-14.1	-453.9	1,878.3	1,410.3				0.0	-22.2	-211.7	1,173.9	940.0
1994	-2.3	58.5	819.0	875.1	-14.1	-451.8	1,880.1	1,414.3	-16.8	-137.1	1,371.9	1,218.0	-22.2	-211.9	1,174.0	939.9
1995	-2.8	58.1	835.3	890.5	-14.1	-449.6	1,881.9	1,418.2	-16.8	-137.1	1,371.9	1,218.0	-22.2	-215.2	2,054.0	1,816.7
1996	1.5	59.1	809.4	870.1	-14.1	-447.5	1,883.7	1,422.1	-16.8	-137.1	1,371.9	1,218.0	-22.2	-217.1	1,415.2	1,175.8
1997	3.7	60.7	813.1	877.5	-14.1	-445.3	1,885.5	1,426.0	-16.8	-137.1	1,371.9	1,218.0	-22.2	-223.5	1,128.9	883.2

1998	4.8	62.9	790.0	857.7	-14.2	-443.2	1,887.3	1,430.0	-16.8	-137.1	1,371.9	1,218.0	-22.2	-233.0	1,370.0	1,114.8
1999	5.4	70.3	815.6	891.3	-14.2	-441.0	1,889.1	1,433.9	-16.8	-137.1	1,371.9	1,218.0	-22.2	-234.3	1,362.8	1,106.4
2000	5.7	76.2	858.9	940.8	-14.2	-438.9	1,890.9	1,437.8	-16.8	-137.1	1,371.9	1,218.0	-22.2	-235.0	1,418.9	1,161.8
2001	22.0	76.8	923.3	1,022.1	-65.6	-365.8	2,213.7	1,782.2	-16.8	-137.1	1,371.9	1,218.0	-22.2	-240.7	1,382.8	1,119.9
2002	30.0	78.7	1,002.6	1,111.3	-65.7	-363.8	2,215.5	1,786.0	-16.8	-137.1	1,371.9	1,218.0	-22.2	-251.4	1,619.4	1,345.9
2003	33.7	87.8	1,044.6	1,166.2	-65.8	-361.7	2,217.2	1,789.7	-86.4	-180.1	2,277.8	2,011.3	-110.5	-291.7	2,806.2	2,404.0
2004	35.4	87.5	1,020.4	1,143.3	-65.8	-359.7	2,219.0	1,793.5	-86.4	-180.1	2,277.8	2,011.3	-110.5	-310.0	2,990.2	2,569.7
2005	35.9	101.7	939.1	1,076.7	-65.9	-357.6	2,220.8	1,797.3	-86.4	-180.1	2,277.8	2,011.3	-110.5	-335.9	2,311.8	1,865.4
2006	78.2	83.8	870.3	1,032.3	-200.9	-436.5	1,428.3	790.9	-98.7	-280.4	1,318.5	939.3	-113.8	-377.7	1,922.1	1,430.6
2007	98.6	86.5	764.1	949.2	-201.1	-435.1	1,429.7	793.5	-98.7	-280.4	1,318.5	939.3	-113.8	-381.3	1,722.3	1,227.2
2008	108.0	93.2	682.2	883.4	-201.3	-433.6	1,431.1	796.1	-98.7	-280.4	1,318.5	939.3	-113.8	-391.6	1,817.8	1,312.4
2009	111.8	108.7	643.7	864.2	-201.5	-432.2	1,432.5	798.8	-98.7	-280.4	1,318.5	939.3	-113.8	-398.0	1,029.5	517.7
2010	112.7	106.2	611.6	830.6	-201.7	-430.8	1,433.9	801.4	-98.7	-280.4	1,318.5	939.3	-113.8	-410.0	883.7	359.9
2011	84.9	109.9	594.4	789.1	-113.8	-289.7	847.1	443.5				0.0	-113.8	-410.4	850.5	326.3
2012	34.2	118.0	597.4	749.5	-113.9	-289.2	847.6	444.6				0.0	-113.8	-410.5	776.1	251.8
2013	8.3	124.2	552.3	684.8	-114.0	-288.6	848.2	445.7				0.0	-113.8	-410.6	892.4	368.0
2014	-5.2	126.0	533.7	654.5	-114.0	-288.0	848.8	446.7				0.0	-113.8	-411.8	778.7	253.1
2015	-12.3	125.3	519.8	632.8	-114.1	-287.4	849.3	447.8				0.0	-113.8	-411.8	870.6	345.1

The Amazon and Cerrado FRELs

Brazil submitted in 2014 a forest reference emission level (FREL) for historical emissions from deforestation in the Amazon Biome[138]. It accounts for primary forest cover loss in the Amazon Biome and includes CO_2 emissions only associated with C stock losses in the aboveground and belowground biomass pools and litter pool. When forest cover loss is detected, it assumes instantaneous oxidation of all C stocks (biomass and litter) contained in forests and does not include CO_2 removals associated with subsequent vegetation regrowth[139]. The FREL value for the period 2006-2010 is 1,106[140] $MtCO_2$/yr (average CO_2 emissions across the period 1996-2005), for the period 2011-2015 is 908[141] $MtCO_2$/yr (average CO_2 emissions across the period 1996-2010) and 2016-2020 is 750[142] $MtCO_2$/yr (average CO_2 emissions across the period 1996-2015).

In 2016, Brazil submitted a reference level for historical emissions from deforestation in the Cerrado Biome[143]. It accounts for conversion of natural forests based on a year 2000 map; which means that re-clearing of forest regrowth on previously cleared land is not included. It includes CO_2 emissions only associated with C stock losses in the aboveground and belowground biomass, dead wood and litter pools. As with the Amazon FREL, it assumes instantaneous oxidation of all C stocks (biomass and DOM) contained in forests and does not include CO_2 removals associated with any subsequent vegetation

[138] The Amazon Biome covers approximately 419.7 Mha, equals to 49.3% of the national territory and 65% of total Brazilian forest area

[139] Brazil notes that 20% of deforested areas regrow to secondary forest that may subsequently be cleared again and that because such cycles of re-growing and re-clearing balance out to 0 net gains and net losses, the exclusion of CO_2 removals associated with subsequent regrowth is justified. However, considering that CO_2 removals associated with subsequent vegetation regrowth will be resident for a time period in terrestrial C stock, and that will have an impact on the atmospheric [GHG] and therefore on the mitigall Amazon biome, ation accounted by the activity, their exclusion will overestimate the net impact of the primary forest cover loss to the atmospheric [GHG] and consequently will overestimate the accounting for mitigation achieved through the reduction of forest cover loss in primary forest.

[140] 1,106,027,616.63 tCO_2

[141] 907,959,466.33 tCO_2

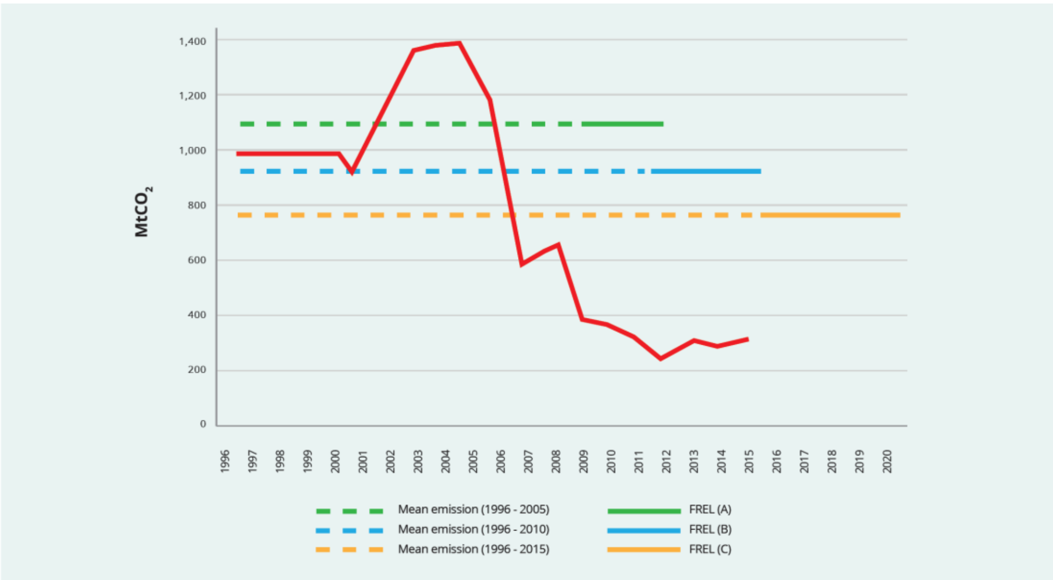
[142] 750.234.379,99 tCO_2

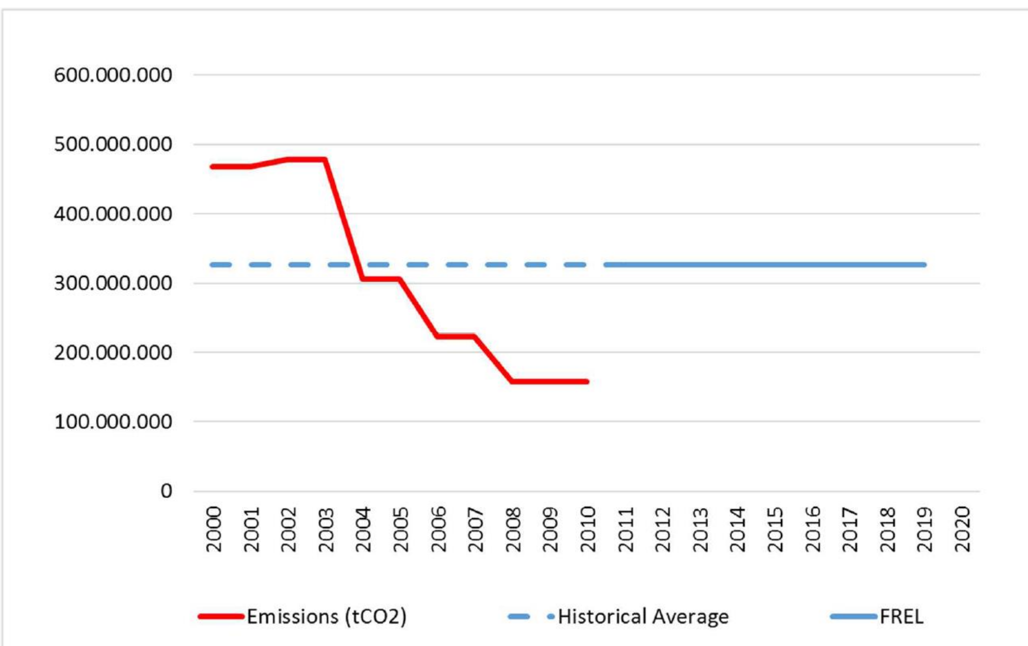
[143] 203,644,800 ha or about 24% of the national territory and 16% of total Brazilian forest area

regrowth. The FREL value for the period 2011-2020 is 327[144] Mt CO_2 (average CO_2 emissions across the period 2001-2010).

Amazon and Cerrado FRELS

In red the historical 1996-2015 emissions from deforestation





[144] 326.672.509 $tCO_2\ yr^{-1}$

Other Brazilian data sources

In addition to the GHGI and REDD-plus reports, other Brazilian data sources on land sector are available:

Projeto de Monitoramento do Desmatamento dos Biomas Brasileiros por Satélite[145] **(PMDBBS)** is a project implemented by the Brazilian Ministry of Environment (MMA) that aimed to provide data on deforestation across the entire country with a harmonized methodology and dataset. The methodology identifies and maps, through visual interpretation, conversions of forest land to other land uses by comparing (wall-to-wall) the 2002 Map of vegetation cover of Brazilian Biomes, scale 1:250,000, of the MMA (Probio, year zero map)[146], with CBERS satellite images, and where needed also Landsat-5 satellite images, with 20x20 meters spatial resolution covering the entire country. New deforested areas are estimated for the time periods: 2002-2008, 2008-2009, 2009-2010, 2010-2011. The entire thematic mapping process is performed using the interpretation scale of 1:50,000.

Results of PMDBBS[147]							
Time period	2002-2008*	2009	2010	2011	2001-2010	Difference with FREL	Difference with GHGI
Biome	ha				Mha		
Amazon	PRODES data for Legal Amazon used				-		
Cerrado	8,507,400 (1,417,900)	763,600	646,900	724,700	11.1[148]	-3.6	-1.1
Caatinga	1,657,900 (276,317)	192,100	-	-	2.3[149]	-	-2.5
Atlantic	274,236 (45,706)	24,800	-	-	0.3[58]	-	-5.4
Pampa	133,408 (45,706)	33,124	-	-	0.2[58]	-	-0.3
Pantanal	427,900 (45,706)	18,800	-	-	0.5[58]	-	-0.2

**The average annual rate in parentheses.*

Mapbiomas is a Project of annual mapping (scale 1:250,000) of land cover/use of Brazil, using Landsat images, and automatic classification, based on NDFI[150], with validation. Data published (http://mapbiomas.org) allows the estimation of net forest area change for each Biome for the time period 2009-2015. Surprisingly, in many years for many biomes the net forest area change is positive (forest regrowth plus afforestation), see Table 8 in Annex II.

System Study Greenhouse Gas Emissions Estimates (SEEG)[151] is a Climate Observatory initiative comprising the production of annual estimates of GHG emissions and removals. The information provided on the data and method used, however, lacks of transparency. The current understanding is that activity data are PRODES data for Amazon Biome and data from PMDBBS for other biomes, together with emission factors derived from the 2nd NC GHGI, to estimate gross emissions from forest cover loss as well as

[145] http://siscom.ibama.gov.br/monitora_biomas/
[146] Ministério do Meio Ambiente (MMA). 2004. PROBIO Final Report - Uso e Cobertura da Terra na Floresta Amazônica. Available on the world-wide web: http://mapas.mma.gov.br/geodados/brasil/vegetacao/vegetacao2002/Amazon/documentos/relatorio_final.pdf.
147 http://siscom.ibama.gov.br/monitora_biomas/index.htm
[148] Assuming that in the year 2001 the rate of deforestation has been equal to that registered in the period 2002-2008
[149] Assuming that in the year 2001 the rate of deforestation has been equal to that registered in the period 2002-2008, and in the year 2010 as the deforestation rate of the year 2009
[150] Normalized Difference Fraction Index
[151] http://seeg.eco.br/en/panorama-mudanca-de-uso-da-terra/

removals in managed forest land. Consequently, the same C pools and GHG from the same land categories as reported in the GHGI are estimated.

Brazilian Biomes Environmental Monitoring Program (PMABB) was established by the Ministry of the Environment for the monitoring of deforestation, land cover and land use, selective logging, forest fires and recovery of native vegetation, through MMA Ordinance no. 365, of November 27, 2015. For the Amazon and the Cerrado biomes, the Program provides for the assessment of deforestation in previous years, proving inputs for the construction of Forest Reference Emission Levels for REDD+. The Program also provides for gradually extending the monitoring conversion of natural vegetation, land cover and land use to cover all Brazilian biomes. The monitoring of forest fires outbreaks throughout the national territory is being upgraded, to produce numeric data on the area affected by fire. Monitoring selective logging in the Amazon will be strengthened. Monitoring of native vegetation restoration will be devised and implemented for the Amazonia, Cerrado and the Atlantic Forest biomes. This information will support decision-making regarding activities to foster the conservation of Brazilian biodiversity, along with informing a strategic vision for territorial management that reconciles diverse interests related to land use and enable Brazil to develop on a more sustainable basis. The Program coordinates the efforts by several Federal Government agencies engaged with satellite based monitoring of land cover and land use (such as EMBRAPA, IBGE, IBAMA, INPE and research institutions) seeking to promote joint actions to produce various mappings for all the Brazilian biomes at different cartographic and time scales, according to the characteristics of each theme, to produce and make standardized, systematic and updated official information available.

(b) Canada

FAO FRA estimates refers to the publication *New estimates of CO_2 forest emissions and removals: 1990–2015* (Federici et al., 2015) where the methodology applied for estimating changes in Biomass for FL and for FL-L is reported.

For preparing data contained in Table 2, the same methodology is applied to DOM. For SOM, it has been assumed that deforestation causes the loss of one-third of the SOC while afforestation determines a symmetrical gain of one-third of the SOC.

Canada’s fluxes for the period 2011-2015 have been estimated by linear extrapolation from FRA data reported by Canada for the years 2000-2010, since Canada’s has not reported data for the year 2015.

A comparison for the 5-year period 2006-2010 among FAO FRA and GHGI is reported in the table here:

Source	F→F	NF→F	F→NF	Total	C pool	GHG
	Mt CO2eq yr^{-1}					
GHGI - 2017	24.3 (28.3)	-0.9	10.4	33.7 (37.7)	AGB, BGB, DOM	CO_2
FAO FRA	51.9	-146.5*	164.3*	69.7	AGB, BGB, DOM	CO_2
* net forest area changes; derived using net change in planted forest (for NF→F) or natural forest (for F→NF)						

Note that both estimates compared in this table have same pools and GHG coverage. Furthermore, FRA data 2006-2010 submitted by Canada were estimated with the same model currently applied to GHGI estimates although with an older version (from GHGI 2013).

Table 1: GHG emission and removals, expressed in CO_2-Ceq and CO_2eq from FL, as reported in the CRF tables of the 2017 Canadian GHGI

(plus C stock losses associated with roundwood export as estimated by using FAOSTAT data and a conversion factor tC/m^3 as derived from data on HWP reporting)

FL	biomass		DOM		SOM	Fire	Harvest	Deforestation	HWP	Total Balance without HWP	Total Balance with HWP
	gain	loss	dead wood	litter	mineral		from HWP inflow				
Year	kt C									Mt CO_2	
1990	672,112.835	-620,616.250	34,836.432	-24,624.749	8,076.215	-978.495	-48,731.241	-4,318.649	11,935.209	-56.5	-101.5
1991	673,778.768	-619,775.169	33,532.054	-25,335.410	8,134.999	-2,497.090	-47,839.761	-4,049.982	9,719.694	-57.0	-94.1
1992	676,287.567	-624,125.020	35,506.752	-25,201.926	8,230.478	-2,443.054	-49,965.899	-3,830.616	9,719.914	-50.5	-88.7
1993	677,230.847	-626,076.647	36,021.412	-25,267.679	8,279.816	-2,149.748	-51,541.752	-3,631.294	10,143.182	-45.5	-84.4
1994	680,652.424	-631,127.373	37,739.119	-25,305.781	8,350.833	-1,865.482	-53,730.320	-3,465.426	11,062.022	-39.5	-81.8
1995	676,698.961	-631,232.468	39,002.425	-25,420.827	8,336.681	-1,739.776	-54,789.905	-3,235.412	11,059.073	-26.5	-68.5
1996	677,437.205	-630,872.969	37,712.127	-25,710.191	8,294.712	-1,607.853	-53,358.834	-3,189.342	11,004.598	-30.7	-72.3
1997	679,285.077	-633,055.695	38,027.056	-25,943.527	8,321.511	-1,363.847	-54,601.399	-3,075.199	12,206.551	-27.0	-72.6
1998	675,438.433	-627,420.077	35,348.121	-26,222.278	8,257.810	-1,238.033	-52,811.361	-3,044.855	12,683.641	-28.2	-77.0
1999	674,664.341	-632,003.094	39,533.136	-25,809.892	8,292.013	-1,231.975	-57,972.313	-2,997.504	15,931.928	-6.6	-67.5
2000	670,079.568	-630,328.215	40,080.345	-26,234.675	8,240.658	-1,362.226	-58,763.583	-2,943.134	15,056.152	7.8	-50.7
2001	666,501.269	-626,638.611	38,978.379	-26,606.924	8,161.167	-1,010.068	-54,335.026	-2,888.763	15,431.723	-3.6	-64.5
2002	657,018.933	-625,425.566	44,343.479	-26,219.781	8,110.341	-1,012.326	-57,502.361	-2,903.997	16,324.981	18.1	-46.7
2003	651,668.636	-624,656.132	47,142.992	-26,485.302	8,037.440	-1,061.020	-52,932.616	-2,844.368	16,006.072	9.8	-54.5
2004	652,514.147	-635,840.311	54,577.644	-26,316.432	8,111.051	-1,023.239	-59,507.127	-2,818.190	16,911.609	42.0	-24.2
2005	648,193.248	-632,017.976	53,667.854	-26,727.445	7,967.433	-1,131.981	-58,026.437	-2,759.216	16,426.203	45.9	-20.5
2006	645,843.725	-628,801.998	49,838.534	-28,081.333	7,860.131	-994.312	-53,007.203	-2,800.606	14,864.767	42.3	-17.3
2007	641,719.628	-613,283.827	38,323.339	-28,910.884	7,689.885	-999.220	-47,807.594	-2,760.843	11,442.590	26.2	-19.8
2008	647,656.487	-603,168.094	22,699.307	-30,949.213	7,663.573	-902.925	-41,261.328	-2,690.915	5,065.243	6.7	-15.1
2009	651,225.781	-601,317.157	19,556.622	-31,120.039	7,794.847	-768.532	-35,310.738	-2,547.383	377.500	-24.4	-28.9
2010	648,406.745	-610,647.108	28,514.507	-29,952.283	8,005.788	-960.979	-41,991.311	-2,453.515	4,034.386	8.4	-10.8
2011	650,168.337	-608,652.838	24,799.945	-29,913.240	8,088.410	-942.987	-44,003.452	-2,441.041	5,359.455	16.9	-9.0
2012	650,458.966	-602,701.827	19,679.518	-29,878.887	8,114.178	-1,025.713	-44,665.926	-2,416.544	6,224.638	15.7	-13.9
2013	652,623.987	-604,278.166	18,942.554	-29,993.924	8,163.443	-984.560	-45,218.549	-2,377.998	6,642.060	19.2	-12.9
2014	652,506.808	-601,986.214	17,433.065	-29,984.735	8,153.626	-857.461	-44,755.419	-2,334.169	6,333.218	13.9	-16.5
2015	650,487.466	-600,552.280	17,791.038	-30,153.424	8,144.707	-854.186	-44,668.237	-2,321.114	6,918.400	14.2	-17.6
Sum 1990-2004	10,061,369.012	-9,419,193.598	592,381.473	-386,705.374	123,235.727	-22,584.230	-808,383.499	-49,236.733	195,196.347	-293.861	-1,048.957
Sum 2005-2015	7,139,291.177	-6,707,407.485	311,246.284	-325,665.408	87,646.021	-10,422.855	-500,716.195	-27,903.343	83,688.460	184.985	-182.441

Table 2: C stock gains and losses and total CO_2 net emission from FL, as reported in the CRF tables of the 2017 Canadian GHGI[152]

FL	biomass		DOM		SOM	Fire[153]	Harvest	Deforestation	HWP	Total Balance without HWP	Total Balance with HWP
	gain	loss	dead wood	litter	mineral		from HWP inflow				
Year	kt C									Mt CO_2	
1990	672,112.835	-620,616.250	34,836.432	-24,624.749	8,076.215	-854.084	-48,731.241	-2,873.307	11,935.209	-63.5	-107.3
1991	673,778.768	-619,775.169	33,532.054	-25,335.410	8,134.999	-2,182.622	-47,839.761	-2,799.250	9,719.694	-64.2	-99.9
1992	676,287.567	-624,125.020	35,506.752	-25,201.926	8,230.478	-2,142.567	-49,965.899	-2,717.662	9,719.914	-58.2	-93.8
1993	677,230.847	-626,076.647	36,021.412	-25,267.679	8,279.816	-1,884.566	-51,541.752	-2,626.219	10,143.182	-51.8	-89.0
1994	680,652.424	-631,127.373	37,739.119	-25,305.781	8,350.833	-1,635.305	-53,730.320	-2,539.354	11,062.022	-45.5	-86.0
1995	676,698.961	-631,232.468	39,002.425	-25,420.827	8,336.681	-1,522.505	-54,789.905	-2,443.971	11,059.073	-31.6	-72.2
1996	677,437.205	-630,872.969	37,712.127	-25,710.191	8,294.712	-1,410.931	-53,358.834	-2,362.207	11,004.598	-35.7	-76.0
1997	679,285.077	-633,055.695	38,027.056	-25,943.527	8,321.511	-1,196.321	-54,601.399	-2,286.158	12,206.551	-31.4	-76.1
1998	675,438.433	-627,420.077	35,348.121	-26,222.278	8,257.810	-1,086.558	-52,811.361	-2,223.110	12,683.641	-34.0	-80.5
1999	674,664.341	-632,003.094	39,533.136	-25,809.892	8,292.013	-1,081.683	-57,972.313	-2,169.671	15,931.928	-12.7	-71.1
2000	670,079.568	-630,328.215	40,080.345	-26,234.675	8,240.658	-1,196.382	-58,763.583	-2,132.100	15,056.152	0.9	-54.3
2001	666,501.269	-626,638.611	38,978.379	-26,606.924	8,161.167	-885.948	-54,335.026	-2,085.452	15,431.723	-11.3	-67.9
2002	657,018.933	-625,425.566	44,343.479	-26,219.781	8,110.341	-889.484	-57,502.361	-2,056.486	16,324.981	9.6	-50.2
2003	651,668.636	-624,656.132	47,142.992	-26,485.302	8,037.440	-929.328	-52,932.616	-2,020.671	16,006.072	0.6	-58.0
2004	652,514.147	-635,840.311	54,577.644	-26,316.432	8,111.051	-899.235	-59,507.127	-2,001.471	16,911.609	34.3	-27.7
2005	648,193.248	-632,017.976	53,667.854	-26,727.445	7,967.433	-994.411	-58,026.437	-1,976.432	16,426.203	36.4	-23.9
2006	645,843.725	-628,801.998	49,838.534	-28,081.333	7,860.131	-872.930	-53,007.203	-1,966.275	14,864.767	33.7	-20.8
2007	641,719.628	-613,283.827	38,323.339	-28,910.884	7,689.885	-876.915	-47,807.594	-1,955.431	11,442.590	18.7	-23.2
2008	647,656.487	-603,168.094	22,699.307	-30,949.213	7,663.573	-791.953	-41,261.328	-1,940.873	5,065.243	0.3	-18.2
2009	651,225.781	-601,317.157	19,556.622	-31,120.039	7,794.847	-671.111	-35,310.738	-1,900.019	377.500	-30.3	-31.7
2010	648,406.745	-610,647.108	28,514.507	-29,952.283	8,005.788	-837.002	-41,991.311	-1,849.602	4,034.386	1.3	-13.5
2011	650,168.337	-608,652.838	24,799.945	-29,913.240	8,088.410	-826.580	-44,003.452	-1,819.524	5,359.455	7.9	-11.7
2012	650,458.966	-602,701.827	19,679.518	-29,878.887	8,114.178	-894.693	-44,665.926	-1,787.950	6,224.638	6.1	-16.7
2013	652,623.987	-604,278.166	18,942.554	-29,993.924	8,163.443	-865.256	-45,218.549	-1,762.591	6,642.060	8.8	-15.6
2014	652,506.808	-601,986.214	17,433.065	-29,984.735	8,153.626	-752.064	-44,755.419	-1,732.058	6,333.218	4.1	-19.1
2015	650,487.466	-600,552.280	17,791.038	-30,153.424	8,144.707	-748.924	-44,668.237	-1,709.221	6,918.400	5.2	-20.2
Sum (1990-2004)	10,061,369.012	-9,419,193.598	592,381.473	-386,705.374	123,235.727	-19,797.517	-808,383.499	-35,337.087	195,196.347	-394.420	-1,110.140
Sum (2005-2015)	7,139,291.177	-6,707,407.485	311,246.284	-325,665.408	87,646.021	-9,131.838	-500,716.195	-20,399.976	83,688.460	92.171	-214.687

152 http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/can-2017-crf-13apr17.zip

153 Controlled burning only