Sector: LULUCF

GHG Platform INDIA

Prepared by: Dr. Sudha Padmanabha

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Citation	Padmanabha, S. (2016). AFOLU Emissions. Version 1.0 dated July 15, 2016, from GHG platform India: GHG platform - India-2007-2012 National Estimates - 2016 Series http://ghgplatform-india.org/data-and-emissions/afolu.html In instances where this sheet is used along with any other sector sheet on this website, the suggested citation is “GHG platform India 2007-2012 National Estimates - 2016 Series”
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LULUCF Sector:

The IPCC GHG emission estimation approach calculates the annual net flux of carbon between the atmosphere and terrestrial ecosystems based on the changes in vegetation and soil following a change in land use. The IPCC Guidelines use six broad land-use categories to report emissions and removals from land use and land use conversions, which are:

1) Forest Land
2) Cropland
3) Grassland
4) Wetlands
5) Settlements
6) Other Land

Emissions and Removal of CO_2: The emissions and removals of CO_2 for the AFOLU Sector, based on changes in ecosystem carbon stocks are estimated for each land-use category (including both land remaining in a land-use category as well as land converted to another land use). Carbon stock changes are calculated for the entire AFOLU sector estimated as the sum of changes in the land-use categories Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land.

Carbon emissions in the AFOLU occur from (a) loss of above-ground biomass due to extraction in the forests, (b) forest conversion to croplands/waste lands and (c) soil management. Conversely, C removal from the atmosphere occurs when croplands/waste lands are abandoned and forests regrow, so that carbon is accumulated again in vegetation and soil. The main steps in estimation are (a) computation of C removal when forest land remain as forest and (b) computation of C removal or emission from the land converted from one category to other (described category wise in detail in following section). In cases where forest land remained as forest land, C removal from the atmosphere due to biomass growth and loss due to disturbance and biomass removals (both fuel wood and timber) were considered. The annual carbon stock changes for each land-use category is calculated as a sum of changes in all carbon pools of above-ground biomass, below-ground biomass, deadwood, litter, soils and harvested wood products. The carbon stock changes can be estimated by two methods; the process based ***Gain-Loss Method*** and the stock-based approach the ***Stock-Difference Method,*** which is Tier 2 and 3 approach.

Non CO_2 emissions: There are significant emissions from biomass burning. Comprehensive approach for estimating carbon stock changes and non-CO_2 emissions result from fire in the Forest Land (including those resulting from forest conversion), and non-CO_2 emissions in the Cropland and Grassland. Non-CO_2 emissions are addressed for the following five types of burning: (1) grassland burning (which includes perennial woody shrub land and savanna burning); (2) agricultural residues burning; (3) burning of litter, understory and harvest residues in Forest Land, (4) burning following forest clearing and conversion to agriculture; and (5) other types of burning (including those resulting from wildfires). Direct emissions of CO_2 are also addressed for biomass burning.

Methodology or approach for emissions estimation: For the AFOLU sector, there are two approaches to defining the land use for estimating the carbon stock change: Approach 1 which represents land-use area totals within a defined spatial unit, which is often defined by political boundaries and only the net changes in land-use area is tracked through time and exact changes in land-use categories cannot be ascertained. Approach 2 provides an assessment of both the net losses and gains in the area of specific land-use categories and what these conversions represent (i.e., changes both from and to a category) presented as land-use conversion matrix. The matrix form is a compact format for representing the areas that have come under different conversions between all possible land-use categories.

Activity Data and Emission Factors

For the GHG estimation, Approach 2 was followed along with country-specific estimates of activity data and emission/removal factors following the Stock-difference method. Land use matrix for forestland remaining forestland and land converted to forestland is from the biennial reports of Forest Survey of India (FSI). State of Forest Report is published by the FSI on a biennial basis since 1987. Forest cover of the country is mapped through satellite data with a LISS III sensor. All lands which are more than 1 hectare in area and with a Canopy density of more than 10% irrespective of the ownership and legal status is called Forest Cover. Also it does not make any distinction whether the forest is natural or manmade forest, government or private, recorded or not recorded. It includes bamboo, orchards, palm, etc.

For other land-use categories, Agriculture, Grassland and Settlement, the land use and land use change matrix was processed by National Remote Sensing Centre (NRSC), Hyderabad. The Change matrix was done for the years 2006-2008; 2008-2011 and 2011-2013, to coincide with that done by FSI to maintain uniformity of inventory years for estimation.

Emission factors i.e. Above ground biomass, Below ground biomass, Dead wood, Litter and Soil Organic Carbon pools was taken from Forest Survey of India Reports[1]. FSI has made estimation of forest biomass and carbon stock change in the biennial reports for all the pools as per the

[1] FSI. Carbon Stock of India's Forest. Forest Survey of India, Ministry of Environment and Forests, Dehradun.

IPCC Good Practice Guidance. The details of the methodology followed by FSI are given in Chapter 2 of the report[2].

Carbon stock estimates for forestland

FSI has been estimating the carbon stock in the India's forest as per the methodology of IPCC Good Practice Guidance developed by the IPCC. For estimation of the activity data, FSI used the results of wall to wall mapping of forest cover of the country using remote sensing data. For stratification of the activity data, FSI has used two variables namely forest types and canopy density. For estimation of emission factors for different strata, the data of National Forest Inventory (NFI) has been used.

Table 1: Carbon stock in various pools for 2004, 2011 and 2013

Pools	Carbon stock in Forests in 2004 (MtC)	Carbon stock in Forests in 2011 (MtC)	Carbon stock in Forests in 2013 (MtC)	Net Change in Carbon Stock between 2004-2011 (MtC)	Net Change in Carbon Stock between 2011-2013 (MtC)
Above ground	2,101	2,192	2,220	91	28
Below Ground	663	694	695	31	1
Dead Wood	25	27	29	2	2
Litter	121	130	131	9	1
Soil	3,753	3,898	3,969	145	71
Total	**6.663**	**6,941**	**7,044**	**278**	**103**

Source: FSI, 2013 and FSI, 2015

The emission factors for above ground woody biomass of trees and Soil Organic Carbon was developed from regular forest inventory and special studies conducted by FSI. GIS techniques were used for synthesizing the data and to estimate carbon stock under different carbon pools. Based on these assessments, FSI biennially publishes carbon stocks and the change in carbon stock since 1994. Based on the FSI studies, the change in carbon stocks from FSI 2013[3] and FSI 2015[4] are as given in Table 1.

Table 2: Annual changes in carbon stock in Indian Forests between 2007-2012

Pools	Annual Carbon stock Change in Forests between 2007-2011 (MtC)	Annual Carbon stock Change in Forests between 2011-2012 (MtC)	Annual Carbon stock Change in Forests between 2007-2011 ($MtCO_2$)	Annual Carbon stock Change in Forests between 2011-2012 ($MtCO_2$)
Above	13.0	14	47.67	51.33

[2] Chapter 3. Methodology used by FSI in Carbon Stock Accounting. In: Carbon Stock of India's Forest. Forest Survey of India, Ministry of Environment and Forests, Dehradun. http://fsi.nic.in/details.php?pgID=sb_15

[3] FSI, 2013. Chapter 5: Growing Stock, India State of Forest Report 2013. Forest Survey of India. Ministry of Environment and Forests, Government of India, India. http://fsi.nic.in/cover_2013/growing_stock.pdf

[4] FSI, 2015. Chapter 5: Growing Stock, India State of Forest Report 2015. Forest Survey of India. Ministry of Environment, Forest and Climate Change, Government of India, India. http://fsi.nic.in/isfr-2015/isfr-2015-growing-stock.pdf

ground				
Below Ground	4.4	0.5	16.24	1.83
Dead Wood	0.3	1	1.05	3.67
Litter	1.3	0.5	4.71	1.83
Soil	20.7	35.5	75.95	130.17
Total	**39.7**	**51.5**	**145.62**	**188.83**

+ve values for C and CO_2 indicate net removals and –ve values indicate emissions (signs are reversed for reporting)

Table 3: Yearly carbons stock change from forest lands in India

Year	Carbon stock change (MtC)	In $MtCO_2$
2007	-39.71	-145.62
2008	-39.71	-145.62
2009	-39.71	-145.62
2010	-39.71	-145.62
2011	-39.71	-145.62
2012	-51.50	-188.83

+ve values for C and CO_2 indicate net emissions and –ve values indicate net removals

Non CO_2 gases emissions from biomass burning in forest land

Non CO_2 GHG emissions are estimated for the forestland subjected to biomass burning. Activity data for the area of the forest burnt was obtained from FAO[5] and the quantity of biomass burnt per hectare is the average biomass as determined by FSI[6] .

IPCC GPG method is adopted for estimating the GHG emissions from forest fire. Area of forest burnt, mass of fuel burnt and CH_4 and N_2O emissions gave the non-CO_2 emissions (Table 4).

Table 4: Trends in area subjected to forest fire and Non-CO_2 emissions

Year	Area burnt (ha)	CH_4 (Mt CO_2 eq)	N_2O (Mt CO_2 eq)	Total Emissions (Mt CO_2 eq)
2007	107292.11	0.17	0.07	0.25
2008	45482.07	0.07	0.03	0.10
2009	162749.45	0.26	0.11	0.37
2010	186459.6	0.30	0.13	0.43
2011	44733.98	0.07	0.03	0.10
2012	76749.34	0.12	0.05	0.18

Cropland

[5] http://faostat3.fao.org/download/G2/GI/E

[6] FSI. Chapter 4, Forest Carbon Stock at National Level. Carbon stock in India's Forests. Forest Survey of India. Ministry of Environment and Forests, Government of India. http://fsi.nic.in/carbon_stock/chapter-4.pdf

The area under cropland, which is the net sown area, is estimated to be 172.43 Mha in 2006-07 and marginally increased to 173.68 Mha during 2013-14. Cropland includes all annual and perennial crops, temporary fallow land and Plantations and do not qualify as Forest lands. It includes those lands with standing crop (per se) as on the date of the satellite imagery. The crops may be of either Kharif (June-September) or Rabi (October – March) or Kharif Rabi seasons.

The amount of carbon stored in and emitted or removed from permanent cropland depends on crop type, management practices, and soil and climate variables. Annual crops (cereals, vegetables) are harvested each year, so there is no long-term storage of carbon in biomass and hence not accounted. GHGs from Cropland are estimated from perennial woody vegetation in orchards, vineyards, and agroforestry systems and soils. Carbon stored in biomass, depends on species type and cultivar, density, growth rates, and harvesting and pruning practices.

The GHG emissions from change in perennial woody vegetation and soils was estimated for cropland remaining cropland (separately for cropland and woody plantations on croplands) and conversions of forest land and other land category to cropland.

The FSI has made an assessment of trees outside the forests (TOF), which includes tree cover comprising of small patches of trees (<1.0 ha) in plantations and woodlots, scattered trees and farms, homesteads and urban areas as well as trees along linear features such as road, canals and cropland bunds. FSI also provides the growing stock of the trees outside the forestland, which includes all land categories other than forest and including croplands.

The approach adopted for estimating carbon stock changes in cropland is as follows:

i) Change in Biomass Carbon stock in croplands: Carbon stock change in Cropland Remaining Cropland is estimated by taking the tree biomass carbon stock at two periods during 2004 and 2013 (Table 4). Biomass of trees outside the forests is available for the years 2004, 2007, 2009, 2011 and 2013. The rate of change in biomass stocks in terms of carbon is estimated and provided in Table 5. The growing biomass stock of TOF is declining among the successive measurements for the period 2004 to 2013. The rate of change in biomass carbon stock declined by 0.014 tC/ha/yr. These rates of change in biomass stock derived from Table 5 are used for estimating carbon stock change in cropland, grassland and settlements, since the TOF values cover all the non-forest land categories.

Table 5: Trends in changes in biomass in trees outside forest including cropland, grassland and settlements

	2004 (SFR 2005)	2013 (SRF, 2015)
Growing Stock in TOF (Million CUM[7])	1616.244	1573.34
Total in Mt biomass (AGB = GS x density (0.7116) x BEF (1.575) (Based on FSI Report, 2009)[8]	1811.44	1763.35
Total in Mt biomass (BGB: root shoot ratio: 0.27)[9]	489.09	476.11
Total Biomass (AGB+BGB) in Mt	2300.53	2239.46
Total biomass carbon (AGB+BGB) in Mt C (carbon fraction 0.5)	1150.26	1119.73
Rate of change in biomass carbon in MtC/yr	-3.39	
Rate of change in biomass carbon in tC/yr	-3392700.30	
Rate of change in biomass in tC/ha/yr	-0.014	

Further the computation of above ground biomass change between forests (FSI, 2015) and agroforestry (FSI, 2013) gives the changes as -16.45 tC/ha.

Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with soil properties and management practices, including crop type and rotation, tillage, drainage, residue management and organic amendments. The soil organic carbon (SOC) stock difference was estimated based on annual change in SOC obtained from different studies conducted at 2-time interval (Appendix)[i]. SOC stock change data is compiled for cropland category for which literature values are available for two periods to enable calculation of rate of change. This data was compiled for cropland and plantations. The average rate of change in SOC for estimation of net change in carbon stock in croplands and plantations are given in Table 6.

Table 6: Rate of Change of Soil Organic Carbon (SOC) in Plantations and Cropland

Climate Region	Change in SOC (t/ha/yr)	
	Plantations	Cropland
Average SOC Change	**0.270**	**-0.012**

The area of cropland remaining cropland, cropland plantations, and rate of change from other land categories to cropland and the emissions from them are given in Table 7. Cropland in India is a carbon source during the period 2007 to 2012 (Table 7). Cropland was net source of 0.048-0.381 $MtCO_2$ during year 2007-2012 (Table 8).

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[7] Source: India State of Forest Report, 2005, 2009, 2013 and 2015. Forest Survey of India. Ministry of Environment and Forests, Government of India.

[8] Kishan, J., Pandey, R., Dadhwal, V.K. 2009. India's Forest and Tree Cover: Contribution as a Carbon Sink. Technical Paper. Indian Council of Forestry Research and Education, Dehradun. http://www.envfor.nic.in/mef/Technical_Paper.pdf

[9] Based on IPCC, GPG.

Table 7: Annual changes in carbon stock in Cropland between 2007-2012

Cropland Remaining Cropland						
Year	**Area of Cropland (Mha)**	**Rate of change in biomass carbon (tC/ha/yr)**	**Total biomass carbon stock change in (MtC)**	**Rate of change in SOC in tC/ha/yr**	**Total SOC stock change in MtC**	**Total change in biomass and soil carbon in cropland (MtC)**
2007	161.560	-0.014	-2.254	-0.012	-1.970	-4.224
2008	161.560	-0.014	-2.254	-0.012	-1.970	-4.224
2009	161.708	-0.014	-2.256	-0.012	-1.972	-4.227
2010	161.708	-0.014	-2.256	-0.012	-1.972	-4.227
2011	161.708	-0.014	-2.256	-0.012	-1.972	-4.227
2012	162.809	-0.014	-2.271	-0.012	-1.985	-4.256
Cropland Plantations remaining Cropland Plantations						
Year	**Area of Plantations (Mha)**	**Rate of change in biomass carbon (tC/ha/yr)**	**Total biomass carbon stock change in Mt**	**Rate of change in SOC in tC/ha/yr**	**Total SOC stock change in MtC**	**Total change in biomass and soil carbon in cropland (Gg)**
2007	9.370	-0.014	-0.131	0.270	2.534	2.403
2008	9.370	-0.014	-0.131	0.270	2.534	2.403
2009	9.370	-0.014	-0.131	0.270	2.534	2.403
2010	9.370	-0.014	-0.131	0.270	2.534	2.403
2011	9.370	-0.014	-0.131	0.270	2.534	2.403
2012	9.421	-0.014	-0.131	0.270	2.548	2.416
Forest Land Converted to Cropland						
2007	0.026	-16.459	-0.428	-0.012	-0.00032	-0.428
2008	0.026	-16.459	-0.428	-0.012	-0.00032	-0.428
2009	0.043	-16.459	-0.708	-0.012	-0.00052	-0.709
2010	0.043	-16.459	-0.708	-0.012	-0.00052	-0.709
2011	0.043	-16.459	-0.708	-0.012	-0.00052	-0.709

2012	0.032	-16.459	-0.533	-0.012	-0.00040	-0.534
Waste Land Converted to Cropland						
2007	0.727	-0.014	-0.010	0.124	0.09010	0.080
2008	0.727	-0.014	-0.010	0.124	0.09010	0.080
2009	0.413	-0.014	-0.006	0.124	0.05123	0.045
2010	0.413	-0.014	-0.006	0.124	0.05123	0.045
2011	0.413	-0.014	-0.006	0.124	0.05123	0.045
2012	0.688	-0.014	-0.010	0.124	0.08526	0.076
Land Converted to Agriculture Plantations						
2007	0.0002	1.254	0.0003	0.2704	0.0001	0.0004
2008	0.0002	1.254	0.0003	0.2704	0.0001	0.0004
2009	0.0001	1.254	0.0002	0.2704	0.0000	0.0002
2010	0.0001	1.254	0.0002	0.2704	0.0000	0.0002
2011	0.0001	1.254	0.0002	0.2704	0.0000	0.0002
2012	0.0053	1.254	0.0066	0.2704	0.0014	0.0080

+ve values for C and CO_2 indicate net removals and –ve values indicate emissions (signs are reversed for reporting)

Table 8: Trends in changes in carbon stocks and CO_2 emissions in cropland

Year	(MtC)	In $MtCO_2$-e
2007	2.17	7.95
2008	2.17	7.95
2009	2.49	9.12
2010	2.49	9.12
2011	2.49	9.12
2012	2.29	8.40

+ve values for C and CO_2 indicate net emissions and –ve values indicate net removals

Grassland

In India, grassland includes a large number of categories other than forestlands and croplands. These lands are largely used for livestock grazing. Based on NRSC classification, grassland is estimated to be 2.22-2.32 Mha during 2007-2012.

The rate of change in biomass is as described above for cropland. Due to lack of 2-time data, the rate of change in SOC for grassland was determined from the country-specific reference soil organic C stocks and default stock change factors (F_{LU}, F_{MG}, F_I) as given by the IPCC. Annual rates of stock change were calculated as the difference in stocks (over time) divided by the time dependence (D) of the stock change factors (with a default value of 20 years). The reference SOC is as determined by FSI for native forests. Based on the Tier I approach, for F_{LU}, F_{MG} and F_I, a default value of 1, 0.97 and 1 was considered respectively for the rate of change which is for moderately degraded grasslands (IPCC, 2006). The annual SOC change for lands converted to grassland was estimated as the difference on the SOC values from other lands to native vegetation.

The annual change in organic C stocks in mineral soils is estimated using the Eq. 2.25 of the IPCC methodology. Accordingly, the Carbon stock change for the grassland is as follows:

Year	Emissions from Grassland remaining Grassland (Mt C)	Land Converted to Grassland (Mt C)	Total Emissions from Grassland (MtC)
2007	-0.216	0.0153	-0.201
2008	-0.216	0.0153	-0.201
2009	-0.218	0.0000	-0.218
2010	-0.218	0.0000	-0.218
2011	-0.218	0.0000	-0.218
2012	-0.225	0.0370	-0.188
2013	-0.225	0.0370	-0.188

Table 9: Trends in changes in carbon stocks and CO_2 emissions and removals in grassland

Year	Total change in biomass and soil carbon in grassland (MtC)	Total change in biomass and soil carbon in grassland ($MtCO_2$-e)
2007	0.20	0.74
2008	0.20	0.74
2009	0.22	0.80
2010	0.22	0.80
2011	0.22	0.80
2012	0.19	0.69

+ve values for C and CO_2 indicate net emissions and –ve values indicate net removals

The grasslands in India are a net source of 0.74-0.69 $MtCO_2$ during the period 2007-2012 (Table 9).

Settlements

The area under settlement is estimated to be 8-9 Mha, which is less than 2% of the total land use in India. The GHG emissions from settlement are estimated for land that is converted to settlement from other land use. The biomass stock change is estimated using the method and data described for croplands. The annual rate of change in SOC was obtained from literature as the difference of SOC between for croplands and wastelands/settlements (divided by 20 years for the conversion rate based on IPCC methodology). The settlement land category is a net source of CO_2 during the period 2007-2012. (Table 10).

Table 10: Trends in carbon stock in settlements for the period 2000-2010 in tC

Year	Conversion to Settlement (ha)	Total change in biomass and soil carbon in Settlements (tC)	Total change in biomass and soil carbon in Settlements (tCO_2-e)
2007	6.7424	0.93	3.41
2008	6.7424	0.93	3.41
2009	19248.036	2655.26	9735.97

2010	19248.036	2655.26	9735.97
2011	19248.036	2655.26	9735.97
2012	0	0.00	0.00

** Values are shown in tC and tCO_2. +ve values for C and CO_2 indicate net emissions and –ve values indicate net removals*

Land converted may be sources or sinks of CO_2, depending on previous land use, topsoil burial or removal during development, current management, particularly with respect to nutrient and water applications, and the type and amount of vegetation cover interspersed among roads, buildings and associated infrastructure. Mostly croplands and plantations got converted to settlements based on the land use change matrix.

Other Land

Other land includes snow covered area, rocky surfaces, water bodies, etc. The area under other land is estimated to be 53-56 Mha. No GHG emissions and removal estimates are made for other land. Further there is no conversion of forestland or cropland or grassland to other land.

GHG Emissions and Removals from LULUCF Sector during 2007-2012

GHG emissions are estimated using the IPCC-2006 guidelines for the dominant 4 land categories Forests, Cropland, Grassland and Settlement. Tier 2 and Tier 3 approach with data from national sources are largely adopted for the GHG estimation. Emissions and removal estimates for each land category are described in the respective land category sections.

Table 11: Estimation of GHG emissions (in CO_2 eq.) for LULUCF sector

Year	**CO_2 emissions and removals ($MtCO_2$)**					**Non CO_2 emissions ($MtCO_2eq$)**		**Total Emissions ($MtCO_2$-eq)**
	Forest-land	**Crop-land**	**Grass-lands**	**Settlements**	**Total CO_2**	**CH_4**	**N_2O**	
2007	-145.62	7.95	0.74	0.000003	-136.93	0.17	0.07	-136.69
2008	-145.62	7.95	0.74	0.000003	-136.93	0.07	0.03	-136.83
2009	-145.62	9.12	0.80	0.009736	-135.69	0.26	0.11	-135.32
2010	-145.62	9.12	0.80	0.009736	-135.69	0.30	0.13	-135.26
2011	-145.62	9.12	0.80	0.009736	-135.69	0.07	0.03	-135.59
2012	-188.83	8.40	0.69	0.000000	-179.75	0.12	0.05	-179.57

** +ve values for CO_2 indicate net emissions and the –ve values indicate net sink of C or net removal of CO_2*

The total national CO_2 and non CO_2 gases emissions and removal estimates for all the land categories are presented in Table 11. It can be observed from Table 11 that forestland dominates the CO_2emissions/removal estimates for India. Forestland is a net carbon sink while agriculture land, grassland and Settlement are carbon sources. Thus, **LULUCF sector is a net sink which was 136.69 $MtCO_2$ in 2007 and has increased to 179.57 $MtCO_2$ during 2012** (Table 11)**.** This is because of large scale afforestation program undertaken by the Government of India.

Appendix

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