Sector: Agriculture

GHG
Platform
INDIA

Prepared by-

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1.Introduction

Scope of the Report

This methodological note comprises the calculation of estimates of greenhouse gas (GHG) emissions of the AFOLU Sector in India at the state level from 2007 to 2012. These estimates are based on the methodology developed by the Intergovernmental Panel on Climate Change (IPCC, 1996; 2006) including variations proposed by the Ministry of Environment and Forest, Govt. of India, the nodal ministry responsible for reporting to United Nations Framework Convention on Climate Change (UNFCCC).

According to this methodology, the estimate of GHG of the AFOLU Sector covers the cropping and livestock production and land-use change activities. The methodology proposed is complemented with some emission factors developed for Indian national conditions and thus, no longer have Tier 1 level (default values), but a Tier 2 level, and at times Tier 3 level according to the classification of the Intergovernmental Panel on Climate Change (IPCC, 1996; 2006). Obtaining specific factors is stimulated by IPCC, since they lead to increased accuracy of the obtained results.

In addition, for the period covered in the present methodology, the effort predominantly used as a basis for activity data (i.e. census data animal population, area and agricultural production) surveys periodically done by the Indian Govt. departments, which are available in various open source databases in the literature, cited throughout this document. All databases and calculations were performed using the Microsoft Excel® software.

Brief description of the Indian AFOLU sector

Agriculture

Agriculture is an important sector of economy in India contributing to about 14% of the Gross Domestic Product. Nearly two-thirds of the population depends on agriculture, directly or indirectly, for their livelihood (ICAR, 2015). It is the most widespread economic pursuit, claiming more than 40% of the country's area under land use and national economy is largely dependent on this sector. Agriculture will continue to be important in India's economy in the years to come.

Crop yield is a function of many factors like climate, natural resources, management and available inputs. India has achieved self-sufficiency in food production after the Green Revolution (GR) but retaining the success of the GR has been challenging due to increasing scarcity of resources (labor, water, energy) and cost of production. Indiscriminate use of production inputs like fertilizers has made Indian agriculture more and more GHG-intensive. Agricultural production is a major emitter of GHGs currently accounting for 18.26% of total national GHG emission in India (BUR, 2015). At the same time, recent estimate reports that food production must be increased by 70% to meet the food demand of estimated 9 billion population (CTA-CCAFS, 2011). Being a populous country, it is evident that a large part of this increased productivity will have to be shared by India. Consequently, GHG emission from agricultural production is expected to further increase. At the same time, agriculture is also part of the solution in mitigating climate change: both by reducing GHG emission into the atmosphere and sequestering atmospheric carbon into plant biomass and soil. India's Intended Nationally Determined Contributions (INDCs) to the UNFCCC place greater emphasis on mitigation. GHG emissions quantification from production systems is important in guiding national planning for low-emission development, generating and trading carbon credits, certifying sustainable agriculture practices, informing consumers' choices with regard to reducing their carbon footprints and supporting farmers in adopting less carbon-intensive farming practices (Olander et al., 2013). Since reports submitted to UNFCCC is guided by Government protocols, a civil society initiative will serve as a back-up source of information, indicate possible divergence, if any, and at the same time help in reconciliation of data towards a dependable reporting in a more transparent manner.

Although over the years there have been important productivity improvements in many sectors, Indian agriculture has major technological, economic, social and environmental contrasts. For example, being the second and the third global producers of rice and wheat respectively, practices that are referenced in this sector, such as biomass burning on a large scale adds to the environmental burden. Given the importance of farming for food and energy security, for the economy and the conservation of natural resources and biodiversity, the preparation of this sector for a low-carbon economy and the adaptation to climate change is critical.

Livestock

Animal husbandry is an integral component of Indian agriculture supporting livelihood of more than two-thirds of the rural population. Animals provide nutrient-rich food products, draught power, dung as organic manure and domestic fuel, hides & skin, and are a regular source of cash income for rural households. They are a natural capital, which can be easily reproduced to act as a living bank with offspring as interest, and an insurance against income shocks of crop failure and natural calamities.

India's livestock sector is one of the largest in the world. It has 56.7% of world's buffaloes, 12.5% cattle, 20.4% small ruminants, 2.4% camel, 1.4% equine, 1.5% pigs and 3.1% poultry. In 2010-11 livestock generated outputs worth Rs 2075 billion (at 2004-05 prices) which comprised 4% of the GDP and 26% of the agricultural GDP. The total output worth was higher than the value of food grains. Driven by the structural changes in agriculture and food consumption patterns, the utility of livestock has been undergoing a steady transformation. While the non-food functions of livestock are becoming weaker, their importance as a source of quality food has increased. Sustained income and economic growth, a fast-growing urban population, burgeoning middleincome class, changing lifestyles, increasing proportion of women in workforce, improvements in transportation and storage practices and rise of supermarkets especially in cities and towns are fuelling rapid increases in consumption of animal food products. Between 1983 and 2004, the share of animal products in the total food expenditure increased from 21.8% to 25.0% in urban areas and from 16.1% to 21.4% in rural areas.

While the role of livestock, especially the ruminants, on the emission of methane and the role of manure management on the emission of nitrous oxide is well-acknwledged, the value does not reach critical level in view of the unorganized nature of the sector. The number-driven growth in livestock production may not sustain in the long run due to its increasing stress on the limited natural resources. The future growth has to come from improvements in technology and service delivery systems leading to accelerated productivity, processing and marketing.

Manure management

Manure management in India, like livestock sector, is not fully organized and is disperse in nature. The principal factors affecting GHG emission from animal manure are the amount of manure produced and the portion of the manure that decomposes anaerobically. While major amount of animal manure produced in the rural sector is used as fuel, there are also localized efforts to produce biogas by organizing animal manure collection and management. The quantity of manure is dependent on the quantity produced per animal and the number of animals. The portion of the manure that decomposes anaerobically depends on how the manure is managed. When the manure is stored or treated as liquid (e.g. in lagoons, ponds, tanks or pits), it tends to decompose anaerobically and produce significant quantity of methane. When manure is handled as a solid (e.g. in stacks and pits) or when it is deposited on pastures and range lands it tends to decompose aerobically and little or no methane is produced.

Land Use, Land Use Change and Forestry (LULUCF)

The GHG emissions and removals from the terrestrial ecosystem arise from carbon stock changes in the carbon pools and from non-CO_2 emissions from a variety of sources including biomass burning, soils, livestock enteric fermentation and manure management. The IPCC Guidelines use six broad land-use categories to report emissions and removals from land use and land use conversions (strictly these are a mix of "land use" and "land cover"): (a) Forest Land, (b) Cropland, (c) Grassland, (d) Wetlands, (e) Settlements and (f) Other Land

India has reported its GHG inventory (Table 1) in the following reports:

a. Initial National Communication to the United Nations Framework Convention on Climate Change (Reporting for the base year, 1994) http://unfccc.int/resource/docs/natc/indnc1.pdf
b. Second National Communication to the United Nations Framework Convention on Climate Change(Reporting for the year, 2000) http://unfccc.int/resource/docs/natc/indnc2.pdf
c. Greenhouse Gas Emissions by the Indian Network for Climate Change Assessment (INCCA) (Reporting for the year, 2007) http://www.moef.nic.in/downloads/public-information/Report_INCCA.pdf
d. India First Biennial Update Report (BUR) to the United Nations Framework Convention on Climate Change (Reporting for the year, 2010) http://unfccc.int/resource/docs/natc/indbur1.pdf

Processes for biogenic producion of GHG

Among the three major greenhouse gases, namely CO_2, CH_4 and N_20, CO_2 can orignate both by abiological and biological means. This section of AFOLU is concerned with biological conversion only. In the ecosystem, CO_2 originates from respiration as well as mineralization of organic matter. Biogenic CH_4 is produced through methanogens by organic matter decomposition. In the initial process of decomposition, the fermenting bacteria hydrolyse polysaccharides and further convert sugar monomers to alcohols, fatty acids and H_2. Further, secondary fermentation carried out by syntrophic microorganisms convert them into acetate, CO_2 and H_2. Syntrophy with methanogens is carried out due to consumption of formed H_2 as soon as degradation is accomplished (Conrad, 2007). Other physiological group of fermenting bacteria, i.e., homoacetogenic bacteria ferments sugars directly to acetate. Some of the homoacetogens are able to convert H_2 + CO_2 to acetate which is finally converted to CH_4. Nitrous oxide, another important GHG is also produced biologically through the intervention of two major groups of microorganisms , nemely nitrifiers and denitrifiers that inititally converts NH_3 to NO_3 and ultimately reduced to N_2. In both processes, N2O is evolved.

Sources of GHG-emissions in the AFOLU sector

There are several sub-sectors in the AFOLU sector that result in GHG emissions. The current report combines agriculture sector with land and land use change and forestry sector as per new classification of IPCC (IPCC, 2013). Below is a brief description of the sectors.

- enteric fermentation
- manure management
- rice cultivation
- burning of agricultural (crop) residues
- Land and land use change and forestry

Table 1. India's national greenhouse gas inventories (in Gigagrams) of anthropogenic emissions by sources and removal by sinks as reported in various reports

	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	CO_2 Equivalent
A. First NATCOM Report (Reporting for the base year 1994)					
1. AGRICULTURE			**14175**	**151**	**344485**
Enteric fermentation			8972		188412
Manure management			946	1	20176
Rice cultivation			4090		85890
Agricultural Crop Residues			167	4	4747
Emission from soils				146	45260
2. LULUCF	**37675**	**23533**	**6.5**	**0.04**	**14292**
Forest and other woody biomass stock		14252			(14252)
Forest and Grassland Conversion	17987				17987
Biomass burning			6.5	0.04	150
Land management		9281			(9281)
Emissions and removals from soils	19688				19688
B. Second NATCOM Report (Reporting for the year 2000)					
1. AGRICULTURE			**14088.3**	**192.73**	**355600.19**
Enteric fermentation			10068.7		211429.43
Manure management			241.19	0.07	5087.77
Rice cultivation			3540.98		74360.56
Agricultural Crop Residues			238.06	6.17	6911.96
Emission from soils				186.49	57810.47
2. LULUCF		**236257.43**	**552.38**	**6.74**	**(222567.43)**

Forest and other woody biomass stock		217393.8	552.38	6.74	203704.42
Forest and Grassland Conversion		18788.08			18788.08
Settlements		75.55			75.55
C. INDIAN NETWORK FOR CLIMATE CHANGE ASSESSMENT (INCCA) (Reporting forthe year 2007)					
1. AGRICULTURE			**13767.80**	**146.07**	**334405.50**
Enteric fermentation			10099.80		212095.80
Manure management			115.00	0.07	2436.70
Rice cultivation			3327.00		69867.00
Soils				140.00	43400.00
Burning of crop residues			226.00	6.00	6606.00
2. LULUCF	**98330.00**	**275358.00**			**-177028.00**
Forestland		67800.00			-67800.00
Cropland		207520.00			-207520.00
Grassland	10490.00				10490.00
Settlement		38.00			-38.00
Wetland					
Other land					
Fuel wood use in forests	87840.00				87840.00
D. INDIA FIRST BIENNIAL UPDATE REPORT (BUR) to the UNFCCC (Reporting for the year 2010)					
1. AGRICULTURE			**14612.78**	**268.70**	**390165.14**
Enteric fermentation			10811.12		227022.52
Manure management			130.60	0.08	2768.11
Rice cultivation			3398.47		71376.95
Agricultural soils				261.55	81080.50
Burning of Crop residues			272.59	7.07	7915.06
2. LULUCF	**58261.70**	**314586.77**	**153.02**	**1.87**	**-252531.78**
Forestland		203829.60	153.02	1.87	-200036.31
Cropland		110757.17			-110757.17
Grassland	55646.16				55646.16
Settlement	2615.54				2615.54

Enteric fermentation - Enteric fermentation takes place in one of the stages of the digestion of herbivorous ruminants (such as cattle, buffaloes, sheep and goats). When the animal eats, the ingested plant material is fermented by microbes in the rumen, in an anaerobic process in which cellulosic carbohydrates are converted into short-chain fatty acids, which are an energy source for the animal. This process generates H_2, used by methanogenic bacteria to reduce CO_2 to CH_4, extracting the energy that ultimately results in the formation CH_4, which is then expelled to atmosphere by the animal. Herbivores monogastric animals (ruminants), such as horses, mules and donkeys, also emit CH_4, however, to a lesser extent, by non-fermenting ingested food during digestion. The enteric fermentation is the largest CH_4 emission source in the country, and the emission intensity depends on several factors such as species, food type, intensity of their physical activity and climatic comfort (IPCC, 2006).

Manure management **–** When the organic material of animal waste decomposes under anaerobic conditions, methanogenic bacteria can produce significant amounts of CH_4. These conditions are favored when the manure is stored in liquid form (in ponds, marshes and treatment tanks), which is more common in animals in feedlot management systems (i.e. swine raising facilities). By having nitrogen, the waste also lead to N_2O emissions during its management. These occur through chemical reactions mediated by microorganisms, called nitrification and denitrification, which transforms the nitrogen contained in manure during management.

Rice cultivation **–** Rice grown in flooded or lowland areas is a major source of CH_4 emissions due to the anaerobic decomposition of organic matter present in the water. In India, rice is produced in diverse ecologies varying from flooded to dry (upland-rainfed rice). Factors such as temperature, solar radiation, organic manure, plant biomass, type of farming, and type of management or farming system, carbon substrate availability and soil type affect the intensity of methane emissions in the irrigated rice.

Burning of agricultural (crop) residues - The burning of cropping residues in the field generates CO_2, N_2O and other nitrogen oxides (NOx), carbon monoxide (CO) and CH_4. The CO_2 emitted does not count because it was offset by the absorption of CO_2 in photosynthesis which generated biomass. In India, biomass burning takes the shape of a major environmental problem in the rice-wheat system of Indo-gangetic plains where farmers resort to residue burning on a large scale for vacating the fields for planting the rabi crop apart from controlled burning of bagasse (sugarcane residues) or cotton wastes.

Land and Land use change - The emission of N_2O in agricultural soils resulting from the application of nitrogen fertilizers (both synthetic and animal origin), as well as the deposition of animal waste directly into pasture (not subject to management) as well as in animal manure applied to fields as fertilizer. N_2O emissions occur through processes of nitrification and denitrification of nitrogen contained in and applied to the soil. These processes are mediated by microorganisms and are dependent on biogeochemical factors, as well as the type of agricultural management. Direct and indirect emissions for atmospheric deposition or leaching/runoff of this gas are also considered. The mineralization of organic soils is also a source of N_2O. However, being a tropical country with much of arable land being used for cultivation, the quantiy of organic soils is very marginal.

Table 2. Sources of GHG emissions in the AFOLU Sector

Source of emission	CO_2	CH_4	N_2O	HF	CF_4	C_2F_6	SF	NOx	C	NMV
Enteric fermentation										
Manure management										
Rice cultivation										
Crop residues burning										
LULUCF										
AFOLU										

As seen above, the main gases emitted by agriculture are CH_4 and N_2O. However, these gases have different potential to influence global climate change when present in the atmosphere, because they interact with solar radiation with different intensities. Two approaches are often used to determine the impact of these gases in the atmosphere: GWP (Global Warming Potential). The first considers the influence of these gases in changing the Earth's energy balance and the second, the influence on temperature rise. Both are measured for a period of one hundred years and express their results in a common unit, CO2 equivalent (CO2e). However, the GWP is the most widely used approach. The table below shows the equivalence between GHG considered in this study.

Table 3. Equivalence of CH_4 and N_2O gases in relation to CO_2 in terms of global warming potential (GWP) (IPCC, 2007).

Greenhouse Gas	GWP-100
CO_2	1
CH_4	21
N_2O	310

2.Methods for estimation of GHG emissions

2.1 Methane emissions from livestock

Emission Estimation methods adopted in the assessment / estimation of GHG emissions are according to the broad framework of guidelines provided in the “Revised IPCC guidelines 1996” and “IPCC good practice guidance and uncertainty management in National Green House Gas Inventories” supported by the IPCC GPG 2000 and 2003 and IPCC 2006 guidelines with specific deviations/factors used by Indian official submissions like NATCOM II, INCCA and BUR reports. Almost all the data are secondary in nature obtained from published reports/ books/ journals/ websites/ personal communication etc. Nevertheless, most of the activity data on livestock statistics are obtained from published reports/documents of Government source such as the Animal Husbandry department , Ministry of Agriculture. GHGs emission from livestock involves two components:

(i) Methane emission due to Enteric Fermentation (EF)

(ii) Methane and Nitrous Oxide from Manure Management (MM)

2.1.1 Methane Emissions from Enteric Fermentation

Methane production from the digestive process of domesticated animals is a function of several variables including quantity and quality of feed intake, the growth rate of the animals, its productivity (reproduction and/ or lactation) and its mobility. The domestic livestock species that contribute to multiple emission source categories in India are cattle, buffalo, sheep, goats, camels, horses, donkeys and pigs.

Approach: In general, the methodology broadly involves three basic steps for estimating GHG emissions from enteric fermentation and manure management.

1. Division of live stock population into sub-groups and characterizing each sub group.
2. Estimation of emission factor for each sub-group’s population in terms of kg/ GHG/ animal/ year.
3. Multiplication of sub group emission factors by the sub-group population estimate, sub group emissions and sum across all sub-groups to estimate total emission.

These three steps can be performed at varying levels of details and complexity based on IPCC classification (IPCC, 2006) as Simplified approach using default parameters drawn from previous studies (**Tier I approach**) or The more complex approach which requires country specific information on livestock characteristics and manure management practices (**Tier II / Tier III**).

Advantages of Tier 2 / 3 method

1. Country specific estimation of Gross Energy (GE) values.
2. No bias attached in calculations of energy needs (GE values).
3. Energy calculations are based on nutrition of tropical animals and feeding studies on Indian livestock

Table 4. Details of the methods (Tiers) used for diverse livestock groups:

Cattle	: Tier – II (Tier III)Methodology
Buffalo	: Tier – II (Tier III)Methodology
Sheep	: Tier – II (Tier III)Methodology
Goat	: Tier – II (Tier III)Methodology
Camels	: Tier – I Methodology
Horses/ Asses	: Tier – I Methodology
Pigs	: Tier – I Methodology

Derivation of Methane Emission Factor (MEF)

MEF is the average annual emission of methane per animal (kg methane / animal / yr). Selection of emission factors, which are more appropriate for the countries' livestock population, is very crucial to emission estimation estimation of methane vis-à-vis reduction of uncertainty. Derivation of emission factors requires feed intake estimates in terms of gross energy intake (GE) and requires animal performance data such as categorization, characteristic of animal populations and their live weight besides methane conversion factor (MCF).

Livestock Population - Categorization

As a first step, the average annual population of animals is required for each of the category. In India census of livestock is conducted every five years and for the period for which estimation needs to be carried out census data as published (Animal Husbandry Department , GoI reports) are utilized. The statewise data and All India data on livestock with sub-categorisation as adopted in NATCOM projects are utilised for working out MEFs.

The domestic animals are divided into distinct, relatively homogenous groups. As countries are encouraged to carryout emission measurements at finer details (further disaggregating recommended for activity categories and sub categories or to choose to sub-divide the categories on some other basis without changing the nature of the calculations) the animal population is divided into more sub groups wherever data are required and available. Such details are used in respect of cattle, buffalo, sheep and goats. However, these data are aggregated to minimum standard levels of information as proposed in the IPCC methodology for reporting final values. This will help to derive better emission factors. Furthermore, working at finer levels of dis-aggregations, which are appropriate to national circumstances does not change the basic nature of the calculations but helps in arriving at precise emission factors.

The cattle have been sub categorized into homogenous categories i.e., "dairy cattle " and "non-dairy cattle", young cattle below 1 year and above. Dairy cattle in India are comprised of two well-defined segments viz. high producing "cross bred/ improved breeds and low producing "indigenous" (desi or non descript) cows managed with traditional methods. The non-descript cows are relatively smaller dairy cows with low levels of production and milk yield. These two segments are evaluated separately by defining two dairy cattle categories. Data on average milk production of dairy cattle will also be reported separately for these two categories as (average milk produced per day) in the activity data. The guidelines of IPCC Good practices are followed to reduce uncertainty.

Buffalo: As buffaloes contribution to total milk production is very high (more than 50%) they have also been classified into "dairy" and "non-dairy" and similar to cows but without any distinction of higher "breed" or "desi" as the data available are for the combined category.

Table 5. Sub-categorisation of cattle for derivation of MEF purpose

Category	Sub category
a) Mature dairy cows (Mature cows that have calved at least once and used principally for milk production)	▪ "Cross-bred" dairy cows ▪ "Indigenous" (non-descript or desi) dairy cows.
b) Non dairy cattle	▪ Young cattle: a) Below 1 year b) 1-3 years ▪ Others: a) Male (Breeding, Working and Others)

	b) Female (Non-dairy adults)

Goat and sheep are sub categorized to mature (1 year & above) and less than one year for the purpose of arriving at MEF while Camels, horses, pigs and ponies etc**are** reported without any sub classification.

a. Body weight: The data used for the present estimation for all categories and sub categories of bovines are as per Swamy and Bhattacharya, 2006. Infact they are the same as adopted for National inventories NATCOM I and II (assumptions on average weight on All india basis).

Table 6. Categorization of bovines on the basis of average body weight (NATCOM II)

Category		**Average body weight**
Cattle Indigenous	**Dairy**	175
	Non-dairy	
	Mature Males	200
	Mature Females	175
	Youngstock	
	Below 1 year	40
	1 – 3 years	140
Cattle Crossbred	**Dairy**	275
	Non-dairy	
	Mature Males	300
	Mature Females	275
	Youngstock	
	Below 1 year	60
	1 – 3 years	180
Buffalo	**Dairy**	275
	Non-dairy	
	Mature Males	300
	Mature Females	275
	Youngstock	
	Below 1 year	70
	1 – 3 years	180

Table 7. Body weight of Sheep and Goat (Swamy , 2004)

Sl. No.	**Age**	**Average weight (kg)**	
		Sheep	**Goat**
1	0 – 3 months	9.53	9.3

2	3 – 6 months	12.1	11.0
3	6 – 9 months	15.9	16.5
4	1 year	19.1	19.5
5	Adult	26.7	32.2

b. Estimation of Gross Energy (GE) intake:

Dairying in India is still mostly an unorganized sector. Majority of the cattle and buffalo are reared by small hold farmers in rural areas In India and they do not practice any standard feeding practice for rearing ruminant stocks except a few organized farms especially where crossbred cows are managed. However, dairy animals are fed better using local resources as they fetch income through milk and is the source of living for many agricultural families..

The feeding system/standards followed by the countries is crucial to the estimation of GE intake by livestock. In this context the feeding standards as practiced or recommended as per Indian Feeding standards are relevant and used for calculation of Gross Energy (GE) intake/requirement for cattle, buffalo, sheep and goats despite the fact that majority of Indian animals are not fed even according to Indian feeding standards and maintained on subsistence rations of low quality forage and grass except in the case of high milch animals. It is pertinent to mention that GE requirements of animals as per Indian Feeding standards based on dry matter intake (DMI) are very relevant. The DMI intake by cattle and buffalo generally range from 1 to 3% (Swamy and Bhattacharya, 2006)on body weight of the animal depending on species, age and production level. Based on the calculations used in Natcom I and II, the GE intake by bovines (provisional) is calculated (Table 8).

Table 8. Dry Matter Intake (DMI) requirement for Gross Energy (GE) calculation for bovines: Cattle/ Buffalo **(Swamy and Bhattacharya, 2006)**

S. No.	Category of animal	Dry matter intake (%)
1	Dairy animals (milch)	2 – 2.75
2	Dairy animals (dry)	2 – 2.25
3	Heifers	2 – 2.25
4	Working animals	2 – 2.5 (normal work – 3 hrs / day or less)
5	Breeding	2 – 2.5
6	Working and breeding	2.5
7	Young stock	2.4 – 2.5
8	Other animals	1.5 – 2

The total feed intake estimate is converted to Gross Energy (GE) using appropriate conversion factor based on IPCC (2006) guidelines for conversion of feed intake into Gross energy. The conversion factor **(CF)** used for arriving at **GE is 18.45 MJ/kg feed**. It is pertinent to mention here that the GE calculations based on Indian feed values is much less when compared to IPCC values. If Indian feed values are adopted, the EF values will be 12 – 14% lesser in comparison with IPCC values (Swamy and Bhattacharya, 2006).

c. Methane Conversion Factor (MCF)

Methane conversion rate is the extent to which feed energy is converted to methane, which depends on several interacting feed and animal characteristics (including genetic factors). The following methane conversion factors (MCF) as adopted in the NATCOM II by Central Leather Research Institute (CLRI), ChennaiCLRI is used. These values are mainly based on IPCC but marginally corrected based on published data on Indian emission(Swamy and Bhattacharya, 2006).

Table 9. Methane Conversion Factor values adopted for bovines and ovines for derivation of Methane Emission Factors (Swamy and Bhattacharya, 2006)

Category		MCF (%) GE = 18.45 MJ / kg Feed (NATCOM – II)
Cattle (Indigenous)	**Dairy**	6.00
	Below 1 yr.	5.50
	1 – 3 yrs.	5.50
	Non-dairy	
	Male (working, breeding)	6.00
	Male others (not working)	6.00
	Female	6.00
Cattle (Crossbred)	**Dairy**	6.00
	Below 1 yr.	5.50
	1 – 3 yrs.	5.50
	Non-dairy	
	Male (working, breeding)	6.00
	Male others (not working)	6.00
	Female	6.00
Buffalo	**Dairy**	6.00
	Below 1 yr.	5.50
	1 – 3 yrs.	5.50
	Non-dairy	
	Male (working, breeding)	6.00
	Male others (not	6.00

	working)	
	Female	6.00
	Sheep	6.00
	Goat	5.00

Emission Factor Development

Separate emission factors are worked out for "Indigenous", "Crossbred" cattle and Buffalo under dairy (milk and dry), heifers and non-dairy (breeding, working, both, young stock and others).

The equation used for each category is ,

$$EF = (GE \times Y_m \times 365) / 55.65$$

Where,

EF = Emission factor (Kg methane / animal / year)

GE = Gross energy intake (MJ / animal / year)

Y_m = Methane conversion rate which is the fraction of gross energy feed converted to methane

Finally, a common emission factor for each main category (dairy and non-dairy) is arrived at by aggregating emissions of all sub-categories and taking into account their proportional emission (weighed average of emissions and population mix).

2.1.2 GHG emissions from animal manure management

2.1.2.1 Methane emissions from animal manure management

The principal factors affecting methane emission from animal manure are the amount of manure produced and the portion of the manure that decomposes anaerobically. The quantity of manure is dependent on the quantity produced per animal and the number of animals. The portion of the manure that decomposes anaerobically depends on how the manure is managed. When the manure is stored or treated as liquid (e.g. in lagoons, ponds, tanks or pits), it tends to decompose anaerobically and produce significant quantity of methane. When manure is handled as a solid (e.g. in stacks and pits) or when it is deposited on pastures and range lands it tends to decompose aerobically and little or no methane is produced.

To develop precise estimates of emissions for each of the animal manure types defined the following information is required

1. Annual average population by climate region i.e., cool, temperate and warm.
   a) Cool: Animal average temperature below 15^{o}C

b) Temperate: 15°C to 25°C

c) Warm: Above 25°C

2. Manure production based on feed intake and digestibility.
3. Average volatile solids (VS) excretion (kg of dry matter per day). They are the degradable organic material in livestock manure.
4. Methane producing potential (B_o) of the manure, generally measured in terms of cubic meters (M^3) of methane per kg of VS. The maximum methane producing capacity for the manure (B_o) varies by species and diet.
5. Manure management system usage (percent of manure managed with each management systems).

The portions of the manure managed in each management system (wet and dry) are required to be collected for representative animal type. Pasture, daily spread, solid storage, pit storage and dry lot are part of dry management system. The dry management systems do not yield any methane. Liquid/ slurry, anaerobic lagoons and pit storage systems are wet management system and they are the primary source of methane from manure management system. Therefore, proportion of manure management by wet and dry systems under different temperature regions must be estimated before estimating methane.

Since most of the regions of Tamil Nadu experience a temperature range above 25°C, the state has been classified under warm region and the MEF values have been derived using the above mentioned procedure. Table 22 shows the MEF values adopted for manure management.

Table 10. MEF values adopted in the report for Methane Emission from Manure Management

Category	MEF (kg/ year/ animal)
Dairy Cattle	3.50
Non-dairy Cattle	2.00
Buffalo	5.00
Sheep	0.21
Goat	0.22
Horses & Ponies	2.18
Donkeys	1.19
Pigs	6.00

2.1.2.2 Emission of nitrous oxide from manure management

Nitrous oxide emission depends on the N_2 excreted by animals, its quantity, quality and its management. Animal fodders are reported to contain 10 - 40 g Nitrogen (N)/ kg dry matters. The greater part of this nitrogen is organically bound but as total nitrogen content increases so does the nitrate (NO_3). Upon passage through the digestive track, nitrate is reduced via dissimilatory nitrate reduction to NH_3/ NH_4. The nitrate reduction reaction may release small amounts of N_2O in the gut, which may escape during rumination. Animals themselves may be very small sources of N_2O. Direct losses from animals themselves are likely to be very small and are therefore not discussed further.

The proportion of total nitrogen intake that is excreted and partitioned between urine and faeces is dependent on the type of animal, the intake of dry matter, and the nitrogen concentration of the diet. The retention of nitrogen in animal products, i.e., milk, meat, wool and eggs, ranges from about 5 to 20 percent of the total nitrogen intake, generally (IPCC, 2006). The remainder is excreted via dung and urine. For sheep and cattle, faecal excretion is usually about 8g N/kg dry matter consumed, regardless of the nitrogen content of the feed. The remainder of the nitrogen is excreted in the urine and as the nitrogen content of the diet increases, so does the proportion of nitrogen in the urine. In animal production systems, where intake of nitrogen is high, more than half of the nitrogen is excreted as urine (IPCC, 1996).

There are small amounts of mineral nitrogen in faeces but the bulk of the nitrogen is in organic form. About 20-25 percent of faecal nitrogen is water-soluble, 15-25 percent is undigested dietary nitrogen and the remaining 50-65 percent is present in bacterial cells. The concentration of nitrogen in urine varies widely because of factors such as nitrogen content in the diet and consumption of water. Typically over 70 percent of the nitrogen in urine is present as urea and the rest consists of amino acids and peptides.

Production of N_2O during storage and treatment of animal wastes can occur via combined nitrification-denitrification of ammoniacal nitrogen contained in the wastes. The amount released depends on the system and duration of waste management. As fresh dung and slurry is highly anoxic and well buffered with near neutral pH, N_2O production is expected to increase with increasing aeration. Aeration initiates the nitrification-denitrification reactions, and hence makes release of N_2O possible.

Several animal waste management system (AWMS) are considered here:

- Anaerobic lagoons
- Liquid systems
- Daily spread
- Solid storage and dry lot
- Pasture range and paddock
- Used for fuel
- Other systems : N_2O emissions from all AWMS are supposed to be reported under Manure Management with the exceptions:
  - Stable manure that is applied to agricultural soils (e.g., daily spread)
  - Dung and urine deposited by grazing animals on fields (pasture range and paddock)
  - Solid storage and dry lot : These are considered to be emissions from agricultural soil and should be reported as emissions from soil.
  - Manure used for fuel: This is being reported under energy sector

Methodology for Estimating N_2O

As recommended by IPCC (2006) is adopted for estimation after estimating the AWMS qualified under manure management.

$N_2O_{ANIMALS} = N_2O\ (_{AWMS}) = \Sigma[N_{(T)} \text{ x } Nex_{(T)} \text{ x } AWMS_{(T)} \text{ x } EF_{3(AWMS)}]$

where,

$N_2O_{ANIMALS}$ = N_2O emissions from animal production in a country (kg N/ yr)

$N_2O\ _{(AWMS)}$ = N_2O emissions from Animal Waste Management System in the country (kg N/ yr);

$= [N_{(T=1)} \text{ x } Nex_{(T=1)} \text{ x } AWMS_{(T=1)} \text{ x } EF_{3(AWMS)}] + \ldots\ldots\ldots$

$+ [N_{(T=TMAX)} \text{ x } Nex_{(T=TMAX)} \text{ x } AWMS_{(T=TMAX)} \text{ x } EF_{3(AWMS)}]$;

$N_{(T)}$ = number of animals of type T in the country

$Nex_{(T)}$ = N excretion of animals of type T in the country (kg N/animal/yr)

$AWMS_{(T)}$ = fraction of $N_{EX(T)}$ that is managed in one of the different distinguished animal waste management systems for animals of type T in the country (appropriate liquid management systems) as mentioned in Table 4.21 of IPCC (1996)

$EF_{3(AWMS)}$ = N_2O emission factor for an AWMS (kg N_2O-N/ kg of Nex in AWMS)

T = type of animal category

Nitrogen Excretion:

The most important parameters for estimation of Nitrous oxide are the derivation of Nitrogen Excretion that is generally expressed as kg N/ animal/ Year. In the absence of any reliable data from Indian sub-continent the default values are the most appropriate and useful though there are still uncertainties in the values listed in relevant tables of IPCC.

Step 1: Population data of animal category involved in N_2O emissions are taken from the data used for estimation of methane from enteric fermentation and manure management. As per the guidelines **cattle (dairy and non-dairy), pigs and poultry** only account for the Nitrous oxide emissions and other animals like sheep, goat camels, which do not account for manure management under wet system, are eliminated from the category of animals producing N_2O from AWMS.

Step 2: Nitrogen excretion: Default values provided in Table 4-20 (IPCC) are used for estimating nitrogen excretion, per animal though there are still uncertainties in the value. Nevertheless, the emission factors are reasonable for adoption to Indian conditions. The excretion data seem to be in reasonable agreement with Bowman (in press). The values adopted are,

Dairy cattle	-	60 kg N_2/ animal/ year
Non-dairy cattle	-	40 kg N_2/ animal/ year
Pigs	-	16 kg N_2/ animal/ year
Poultry	-	0.6 kg N_2/ animal/ year

Step 3: Nitrogen excretion from different animal waste management systems (N_2-AWMS) - The nitrogen excretion from AWMS systems (Anaerobic lagoon/ liquid system and any other system) are derived as a percentage of N_2 from total N_2 excretion from animals as per IPCC guidelines using tables B-3, B-4, B-6 & 4.21 respectively for dairy & non-dairy cattle, pigs and poultry.

Step 4: The N_2O emission per animal is determined by multiplying the Nitrogen excretion (N_2-AWMS) by using appropriate emission factors (EF_3) of table 4.22.

Emission Factors (EF_3)

Anaerobic Lagoons	- 0.001
Liquid Systems	- 0.001
Other Systems	- 0.005

Emission Factor per Animal is determined by using the equation

$\Sigma(N_2\text{-}AWMS_i) \times (EF_3)_i$.

Step 5: Total emission is determined by multiplying the number of animals in each category with emission factor. Emissions from all categories are aggregated and total emission expressed as Gg N_2O/ year.

Emissions (Gg/ Year) = EF (kg/ head/ year) x population/ 10^6kg/ Gg.

Table 11. MEF values adopted for Nitrous Oxide

Category	MEF
Dairy cattle	0.0006
Non-dairy cattle	0.0004
Pigs	0.0074
Poultry	0.0025

2.2 Agricultural Soils

2.2.1 Direct N_2O Emissions

2.2.1.1 Synthetic nitrogen fertilizers

N2O emission from use of fertilizer

Portion of nitrogenous fertilizers applied in agricultural soil are lost into the atmosphere as direct emission of N2O through the process of nitrification and denitrification as well as indirect conduits such as volatilization losses, leaching and run-off. Therefore, total N2O emissions from agricultural soils are a summation of direct and indirect emissions.

$$Total\ N_2O\ emission = N_2O_{direct} + N_2O_{indirect} \quad \ldots\ldots\ldots(2)$$

Direct Emissions

Direct emission of N2O due to application of N fertilizers in agricultural field was estimated following the approach of Bhatia et al.(2004) and modified to account for volatilization loss of urea and other forms of N as in equation 3.

$$N_2O_{direct} = \{(N_{FERT} - (N_{urea} * V_{gas\ loss} + N_{other} * V_{gas\ loss}) * EF_{direct}) * (44/28))\} \ \ldots\ldots (3)$$

Where,

E_{direct} =*Direct emissions from fertilizers in India (Gg N2O)*

N_{FERT} =*total quantity of N in fertilizer applied to soil (Gg)*

N_{urea} = *quantity of N from urea (Gg)*

N_{other} = *quantity of N from other fertilizers applied (Gg)*

$V_{gas\ loss}$ = *fraction of the N-fertilizer volatilized as* NH_3 *and NOx from Urea application*

EF_{direct}= *N20 emission from applied fertilizer*

$(44/28)$= *conversion factor from N to* N_2O

Indirect Emissions

$$N_2O_{indirect} = N_2O_{(V)} + N_2O_{(L)} \quad (4)$$

$$N_2O_{(V)} = (N_{Urea} * V_{gas\ loss} * EF_3 + N_{Other} * V_{gas\ loss} * EF_3)*(44/28) \quad (5)$$

Where,

$N_2O_{(V)} = N_2O$ is produced from volatilization of applied fertilizer and its atmospheric deposition as NOx and NH4.

N_{urea} = *quantity of N from urea (thousand tonnes)*

N_{other} = *quantity of N from other fertilizers applied (thousand tonnes)*

$FRAC_{gasf}$ = *fraction of the N-fertilizer volatilized as* NH_3 *and NOx from Urea application (%)*

$FRAC_{Oth\,gasf}$ = *fraction of the N-fertilizer volatilized as* NH_3 *and NOx other fertilizer application (%)*

EF_3=*indirectN20 emission from volatilized N fertilizer from urea and other fertilizers (%)*

Fc = *conversion factor from N to* N_2O *(44/28)*

$$N_2O_{(L)} = N_{FERT} * FRAC_{leach} * EF_4 * (44/28) \quad (6)$$

Where,

$N_2O_{(L)} = N_2O$ is produced from leaching and run-off of applied fertilizer

N_{FERT} =*total quantity of N in fertilizer applied to soil (thousand tonnes)*

$FRAC_{leach}$ = *leaching loss of N from applied fertilizer and manure (%)*

EF_4 = *indirect N20 emission factor from leached and run-off N from fertilizers applied to soil*

$44/28$ = *conversion factor from N to* N_2O

Activity data

Database for fertilizer consumption

Data on the quantity of N consumed is needed to calculate direct emission from synthetic fertilizers applied to agricultural soils and this data was available at Indiastat website which also sources data from Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Govt. of India (http://eands.dacnet.nic.in/).

The consumption of total fertilizers has been divided into urea and consumption of other fertilizers. For estimating quantity of urea consumed by all the states, we apportioned share of urea consumption from total nitrogen fertilizers by summing up fertilizers such as Urea, Ammonium Sulphate(A/S), Calcium Nitrate (CAN), Monoammunium Phosphate (MAP) and Diammonium Phosphate (DAP).The quantity of urea in each state was estimated by multiplying the total N fertilizer consumption by the respective proportion of N in that fertilizer. Percentage of urea consumption varied across states and year ranging from 63 to 96 percent in 2007, 67 to 100 percent in 2008, 52 to 97 percent in 2009 and 2010, 71 to 95 to 98 percent in 2011 and 2012 respectively as sgown in Table 12. Quantity of other N fertilizer consumed in each states and UT were obtained by subtracting the urea amount from total N fertilizer.

Factor of N losses from volatilization ($V_{gas\ loss}$) and leaching ($Frac_{leach}$)

For the calculation of the nitrogen loss from volatilizationofNH3andNOx($V_{gasloss}$), a magnitude of 15 percent per kg of urea and other fertilizers was considered instead of IPCC fraction of 10 percentas most Indian soils are low in acidity and high in average temperature therefore resulting in more volatilization losses. The fraction of N lost through leaching is 10 percent of N applied to the soil.

Table 12: Proportion of Urea to total N fertilizer consumption in India from 2007-2012

State	2007	2008	2009	2010	2011	2012
Andaman and Nicobar Island	0.66	0.75	0.72	0.74	0.71	0.72
Andhra Pradesh	0.88	0.87	0.86	0.87	0.87	0.90
Arunachal Pradesh	0.87	0.94	0.94	0.94	0.94	0.96
Assam	0.87	0.89	0.91	0.92	0.93	0.95
Bihar	0.94	0.92	0.92	0.90	0.91	0.91
Chandigarh						
Chhattisgarh	0.90	0.88	0.84	0.83	0.87	0.87
Dadra and Nagar Haveli	0.69	0.70	0.73	0.69	0.72	0.73
Daman and Diu	0.90	0.86	0.89	0.89	0.93	0.99
Delhi	0.92	1.00	0.95	0.95	0.91	0.98
Goa	0.91	0.77	0.78	0.88	0.81	0.84
Gujarat	0.84	0.84	0.82	0.84	0.87	0.90
Haryana	0.90	0.87	0.87	0.88	0.87	0.89
Himachal Pradesh	0.97	0.96	0.94	0.96	0.95	0.92
Jammu and Kashmir	0.89	0.85	0.88	0.80	0.83	0.88
Jharkhand	0.84	0.83	0.83	0.84	0.89	0.91

Karnataka	0.86	0.79	0.80	0.80	0.79	0.89
Kerala	0.93	0.94	0.91	0.89	0.87	0.88
Lakshadweep						
Madhya Pradesh	0.86	0.81	0.81	0.81	0.83	0.82
Maharashtra	0.89	0.86	0.80	0.83	0.86	0.88
Manipur	0.92	0.93	0.97	0.93	0.95	0.96
Meghalaya	0.89	0.92	0.98	0.88	0.92	0.94
Mizoram	0.77	0.68	0.53	0.54	0.96	0.98
Nagaland	0.78	0.77	0.77	0.78	0.77	0.77
Orissa	0.86	0.85	0.84	0.83	0.89	0.89
Puducherry	0.88	0.87	0.92	0.93	0.93	0.93
Punjab	0.90	0.90	0.88	0.89	0.89	0.88
Rajasthan	0.88	0.85	0.85	0.85	0.86	0.89
Sikkim						
Tamil Nadu	0.87	0.87	0.88	0.87	0.86	0.89
Tripura	0.97	0.97	0.97	0.96	0.95	0.96
Uttar Pradesh	0.91	0.90	0.89	0.89	0.89	0.88
Uttarakhand	0.96	0.95	0.94	0.95	0.95	0.96
West Bengal	0.88	0.88	0.87	0.86	0.90	0.89
India	0.89	0.87	0.86	0.86	0.87	0.89

Emission Factor(EF)

Revised N_2O emission factor of 0.7 percent per kg of urea and other N fertilizers applied to the soil after discounting the N lost through volatilization (NH_3 and NOx) and leaching loss of N (Bhatia et al., 2004). The default IPCC emission factor for N_2O emission for atmospheric NH_3 and NOx is 1 percent; however, taking into account characteristics of Indian soils, 0.5 percent emission factor was used for N_2O from volatilized N. Similarly, emission factor used for deposited N from leaching and runoff was 0.5 percent.

2.2.2 Methane emissions from rice cultivation

CH4 emission from Rice Cultivation

Paddy fields hold a large share in total methane emission from agriculture. The method used in Second National Communication (SNC) for estimating annual emissions from rice cultivation in India has been adapted from Gupta et al., 2009 using IPCC 2006 guidelines. The methane emission was estimated by multiplying the total paddy rice area under different water management regimes (ha) with corresponding EF (Table1 equation 1. . Separate calculations were made for each state and union territory (UT) of India and then summed up to estimate the national total.

$$E_{RC} = A_C * EF_W * 10^{-6} \quad \ldots\ldots (1)$$

Where,

E_{RC} *= CH4 emissions from rice cultivation (Gg year*$^{-1}$*),*

A_C*= area of rice cultivation under management C (ha)*

EF_W= factor applied for different types of water management (kg CH_4 ha^{-1})

10^{-6} = to convert Kg into Gg

Step1: We first calculated the percentage of area under rice under respective water management regime for each state.

Step2: Next, we multiplied India specific emission factor of each water management regime with proportion of area under cultivation under each water management across all states in India.

Step 3: To convert data into Kg to Gg, we multiplied by 10^{-6}.

Activity data

Area of rice cultivation (*A_c*)

The total rice harvested area data is collated from Indiastat, an Indian government portal for statistical data of India (Indiastat, 2015). This data is published in thousand hectares for each state. The total harvested area (HA) was classified into 7 categories namely, continuously flooded, intermittently single aeration, intermittently multiple aeration, rainfed flood and drought prone, deep water and upland.

In the absence of documentation of authentic rice water management statistics, apportionment of area under different water management regimes was estimated using expert judgement and cue from Gupta et al., 2009, taking 1994 categorization as an example. Across different states in India the upland rice cultivated area ranged from 0 to 49% and the remaining was lowland ranging from 48 to 100%. Lowland regime further comprised of upto 36% flood and 43% drought prone in India. While, intermittently single aeration was 46% of HA.

Emission Factor

The emission factor used for calculation of GHG emission from different agricultural sectors including from rice cultivation is listed in Table 1 are based on SNC measurements carried out continuously since 1990s (Ministry of Environment & Forests (MoEF), 2012).

Table 13: Emission factors from various agricultural sources in India

Category	Sub-Category	Emission Factor	Unit
Methane emission from rice cultivation[a]	Continuous flooding	162	Kg CH4 ha-1
	Single aeration	66	Kg CH4 ha-1
	Multiple aeration	18	Kg CH4 ha-1
	Deep water	190	Kg CH4 ha-1
	Flood prone	190	Kg CH4 ha-1
	Drought prone	66	Kg CH4 ha-1
	Upland	0	Kg CH4 ha-1
N_2O emission from N fertilizers[b]	Direct emission	0.8	%
	Indirect emission from atmospheric deposition from inorganic fertilizer use	0.5	%
	Indirect emission from leaching and run-off	0.5	%
	Fraction of gas loss through volatilization of N	0.15	%
	Fraction of leaching loss	0.1	%
Emission from Crop Residue Burning[c]	CH_4	2.7	g kg-1
	CO	92	g kg-1
	N_2O	0.07	g kg-1
	NO_x	2.5	g kg-1

Note: a. NATCOM II (Ministry of Environment & Forests (MoEF), 2012
b. Bhatia et al. (2004)
c. Andreae and Merlet (2001)

2.3 Residue burning

After the harvest, agricultural residue left on the field isused for different purposes off-site. In some cases, a part of whole residue after crop harvest is left in the field which is burn *in-situ* for the ease of cultivation for subsequent crop. This burning emits substantial quantity of air pollutants like CO2, N2O, CH4, CO and many other gases. In India, agricultural burning is common in Northern and some eastern states of the country, particularly, Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. Major crop whose residues are partly burnt in India include rice, wheat, maize, cotton, sugarcane, jute, rapeseed-mustard, millets and groundnut(Ministry of Environment & Forests (MEF), 2012). The estimation of emission of targeted crops at state-level was derived by estimating the amount of biomass actually burnt in the field using the IPCC Revised Inventory Preparation Guidelines(IPCC, 1996) and Jain et al.,(2014).

$$EF_{resi} = \sum_{crops} (P_{crop} * R_{ratio} * D_{frac} * C * F_{qc} * EF_i$$

EF_{resi} = Emissions from residue burning

P_{crop} = Annual crop production in thousand tonnes

R_{ratio} =Residue to crop ratio

D_{frac} = Dry matter fraction in the residue

C = Combustion factor of the residue

F_{qc} = Percentage of the crop that is burned

EF_i =Emission factor for corresponding gas (i =methane, nitrous oxide, carbon monoxide and NOx, See table 1 for details).

Step1: We estimated fraction of rice burnt at state-level and for other crops, a generalized value was taken for all the states.

Step2: The amount of crop residue generated was a product of annual crop production, residue to crop ratio and dry matter fraction in the crop biomass.

Step3: Crop residue generated was further multiplied with respective fraction of crop burnt and emission factor of air pollutants to get the value of emission from crop residue burning.

Activity data

Database for residue burning

Crop Production Data

State level crop production data used for estimating emission from residue burning for the period of 2007 to 2012 has been extracted from Indiastat website.

Fractions and emission factors of air pollutants

For residue to crop ratio, Bandyopadhyay et al., 2001 was referred. The emission factor for air pollutants namely, CH4, N2O, CO and NOx was taken from Andreae & Merlet (2001). The fraction of crop burnt varied across states and crops.

Rice straw is not burnt uniformly in India ranging from 8 to 80 percent in India(Gadde et al., 2009) Depending on the usage and knowledge of the farmer, the residue burnt varies in India. Out of the total rice residue generated, after accounting for domestic uses and other activities, surplus is burnt. Since retaining large amount of residue obstructs tillage practices, farmers perceive burning as one of the most inexpensive and quickest methods to get rid of the surplus. The percentage of wheat residue burnt in Haryana, Punjab, Uttar Pradesh and Himachal Pradesh is 13 percent more than rest of the India i.e. 10 percent (Jain et al., 2014). Approximately 10 percent of Cotton and Maize residue are burnt, while sugarcane residue is as high as 25 percent (Jain et al., 2014).

Combustion factor is the rate at which crop residue burns. Different crops have different combustion efficiency. The combustion factor values reported by Turn et al. (1997) for rice, wheat, maize, sugarcane and groundnut have been used by us. Since, direct value for groundnut and rapeseed-mustard combustion efficiency wasn't available; we have used value of other nuts as a proxy for groundnut and oilseeds for rapeseed-mustard (Streets et al., 2003). As a value specific to India for combustion of cotton wasn't accessible, therefore, we used combustion factor as used by Jain et al., (2014) in the report

Table 14: Fraction of crop residue burnt in India

Crop	Fraction Burnt
Wheat	0.1 – 0.23#
Cotton	0.1
Maize	0.1
Groundnut	0.1
Rapeseed-mustard	0.1
Jute	0.1
Sugarcane	0.25
Millets	0.1

Note: # Fraction for Haryana, Uttar Pradesh, Madhya Pradesh and Himachal Pradesh
Source: (Jain et al., 2014)

Table 15: Fraction of Rice Residue burnt in India

State/UT	**Fraction of residue burnt**
Andaman and Nicobar Island	0.08
Andhra Pradesh	0.09
Arunachal Pradesh	0.10
Assam	0.10
Bihar	0.20
Chandigarh	0
Chhattisgarh	0.09
Dadra and Nagar Haveli	0

Daman and Diu	0
Delhi	0
Goa	0.09
Gujarat	0.10
Haryana	0.79
Himachal Pradesh	0.80
Jammu and Kashmir	0.79
Jharkhand	0.20
Karnataka	0.05
Kerala	0.10
Lakshadweep	0
Madhya Pradesh	0.09
Maharashtra	0.09
Manipur	0.10
Meghalaya	0.10
Mizoram	0.10
Nagaland	0.10
Orissa	0.10
Puducherry	0.09
Punjab	0.80
Rajasthan	0.20
Sikkim	0.08
Tamil Nadu	0.09
Tripura	0.10
Uttar Pradesh	0.25
Uttarakhand	0.24
West Bengal	0.10

Source: (Gadde et al., 2009)

3. Converting Equivalent of CO_2 (CO_2e) results to GWP

The results of emissions of $CH_4$and N_2O calculated for all emission sources of the Agriculture Sector were also showed in equivalent of CO_2 (CO_2e) using the GWP metrics, according to the formulas below:

$$\boldsymbol{Emission\ of\ CO_2 e_{GWPi} = \sum[(Emission\ of\ CH_4\ x\ 21) + (Emission\ of\ N_2O\ x\ 310)]}$$

Where:

$Emission\ of\ CO_2 e_{GWPi}$=GHG emission in equivalent of CO_2 (CO_2e) according to Global Warming Potential (GWP) (kg CO_2e)for the emission source *i*

Emission of CH_4 = emission of CH_4(kg CH_4).

Emission of N_2O = emission of N_2O (kg N_2O).

21 = factorfor converting emission of CH_4in CO_2e

310 = factor for converting emission of N_2O in CO_2e

4. Challenges for Methodologies and Assumptions

The emission factors for agriculture sector is based on field emission estimation data collected during 2002-2010 and has been applied to the years 2006-2012 based on emission factors developed by IPCC (IPCC 1996/2006). Scope of improvement with reference to the inventories presented include (i) estimation methodologies for some key categories towards a higher tier of estimations for these categories; (ii) refinement of GHG emission factors developed and (iii) a strong emphasis on QA/QC procedures as identified in IPCC Good Practices Guidance (GPG) 2000 and 2003. The general QA/QC checks for all emission estimation preparations included cross-checking the reliability of the activity data collected from the secondary sources for proper documentation and record; cross-checking for transcription errors in the activity data; consistency, completeness, and integrity of the database; documentation and reporting of the rationale of assumptions used for activity data; documentation and reporting of gaps in the database; consistency in labelling of units in ensuing calculations.

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