Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks



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1990-2011 Analysis

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Foreword

The contribution of agriculture, forestry and fisheries to global emissions of greenhouse gases is well recognized. So are the critical gaps in information, knowledge and capacity development which need to be addressed with urgency. Meeting these challenges can allow member countries to reduce their emissions through changes to management practices that can simultaneously improve productivity, reduce hunger and increase the resilience of production systems in the coming decades.

The new work of FAO on greenhouse gas emissions statistics represents a critical step on this important path. The new FAOSTAT Emissions database, developed jointly by the Climate, Energy and Tenure Division and the Statistics Division, is aimed at improving and disseminating agricultural statistical data for better quantification of greenhouse gas emissions and for the identification of the actions needed to reduce them. This report provides the first comprehensive analysis of the challenges and opportunities that exist to this end in the relevant production sectors, at global and regional level, covering the period 1990-2011.

The new FAO database offers broad support to FAO's member countries and provides benefits to users worldwide which include the increased ability to conduct analyses of greenhouse gas emissions from agriculture, forestry and fisheries at national, regional and global level, as well as the provision of improved and continuously updated statistical knowledge in support of agricultural planning. This is underpinned by the recognition that enhanced national statistics are a pre-requisite for identifying climate-smart solutions which bring improved productivity, resilience and mitigation together in one coherent package.

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Abstract

This report discusses new knowledge on anthropogenic greenhouse gas (GHG) emissions from agriculture, forestry and other land use (AFOLU) activities made available through the new FAOSTAT Emission database. The database is available globally, with country detail, for all agriculture, forestry and land sub-categories available in FAOSTAT and in the Forest Resources Assessment (FRA). GHG emissions are computed from official national activity data and geo-spatial analyses, applying international standard methodologies of the Intergovernmental Panel on Climate Change (IPCC) to ensure consistency with GHG Inventory processes established under the climate convention. The analysis shows increases in emissions of agriculture (from 4.6 to 5.0 Gt CO_2 eq yr^{-1} in 1990s and 2000s; 5.3 Gt CO_2 eq yr^{-1} in 2011), decreases in deforestation rates (from 4.6 to 3.8 Gt CO_2 eq yr^{-1} in 1990s and 2000s; 3.7 Gt CO_2 eq yr^{-1} in 2010), and decreases in forest sinks, albeit with a reversal since the mid-2000s (from -2.9 to -1.9 Gt CO_2 eq yr^{-1} in 1990s and 2000s values; -2.1 Gt CO_2 eq yr^{-1} in 2010). At the same time, the data show that GHG intensity of products (i.e., GHG emissions per unit commodity produced) decreased during 1990-2010, but that if no further mitigation measures and technical efficiency improvements are implemented, future emissions may further increase by up to 30% by 2050. Better information on AFOLU emissions is critical in many developing countries, given the potential to identify and fund actions that can usefully bridge national food security, resilience, mitigation and development goals into one coherent package.

Key words: Greenhouse Gas, Statistics, Mitigation, Agriculture, Forestry, Land Use

JEL codes:

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Acronyms and abbreviations

A	Activity data
AFCAS	African Commission on Agricultural Statistics
AFOLU	Agriculture, Forestry and Other Land Use
AI	Annex I
APCAS	Asia and Pacific Commission on Agricultural Statistics
AR	Assessment report
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
E/R	Net CO_2 emissions/removals
EF	Emission factor
ESS	Statistics Division
FAO	Food and Agriculture Organization of the United Nations
FRA	Global Forest Resources Assessment
GAEZ	Global Agro-Ecological Zones
GAUL	Global Administrative Unit Layers dataset
GEZ	Global Ecological Zones
GFED4	Global Fire Data
GHG	Greenhouse gas
GLC	Global Land Cover dataset
IEA	International Energy Agency
IICA	Instituto Interamericano de Cooperación para la Agricultura
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LDC	Least developed country
MODIS	Moderate Resolution Imaging Spectroradiometer
MOP	Meeting of the Parties
N_2O	Nitrous oxide
NAD	Net area difference
NAI	Non-Annex I
NAMAS	Nationally Appropriate Mitigation Actions
NRC	Climate, Energy and Tenure Division
QA/QC	Quality Assurance/Quality Control
REDD	Reducing emissions from deforestation and forest degradation
SFA	Stable Forest Area
UNFCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistics Division

1. INTRODUCTION

Greenhouse gas (GHG) emissions from fossil fuels grew 1.4% in 2011, reaching a record 31.6 $GtCO_2eq$ yr-1 in 2012, the highest level in history — as documented by the International Energy Agency (IEA, 2013). By contrast, data on GHG emissions from agriculture, forestry and other land use (AFOLU) activities are poorly known, including for recent years. This fundamental gap, including the lack of an international agency reporting AFOLU emissions figures at regular intervals is an obstacle to more precisely characterizing recent total anthropogenic forcing. This furthermore hinders the identification of response strategies necessary today and in coming decades for reducing the threat of climate change on the planet—and the role that could be played by appropriate mitigation actions in the AFOLU sectors. Action in agriculture, forestry and other land use are of significant interest to many countries, especially in non-Annex I countries, where AFOLU activities represent a large portion of national economies, are particularly at risk under climate change, and may benefit significantly from receiving substantial climate funding for climate strategies that strategically link GHG reduction to resilience, food security and rural development goals (FAO, 2011).

Regular updates of AFOLU emission estimates thus matter greatly for both science and policy reasons. Scientifically, improved estimates of anthropogenic forcing and their trends are needed to more reliably project medium to long-term climatic effects and to determine viable mitigation strategies (e.g., Houghton *et al*, 2012; Hansen *et al*, 2012). Politically, improving assessment and reporting of AFOLU emissions provides an improved knowledge base to discussions on the role of agriculture within the United Nations Convention on Climate Change (UNFCCC) Conference of the Parties/Meeting of the Parties (COP/MOP). New mechanisms are needed that link climate change response actions in non-Annex I—and especially least developed countries (LDCs)—with their overarching rural development goals. To this end, the AFOLU sector may potentially benefit from large international funding—up to US$ 100 billion annually under the Green Climate Fund, and including Reducing Emissions from Deforestation and Forest Degradation (REDD) (FAO, 2011; Karsenty, 2012).

The most fundamental problems associated with improving estimates of the AFOLU sector is related to high levels of input data and estimation methodology uncertainty compared to other sectors. While national CO_2 emissions from fossil fuels—which represent the majority of anthropogenic emissions—are characterized by a 10-15% estimation uncertainty, emissions estimates from agriculture (crops and livestock production) have much larger uncertainties, ranging 10-150% (IPCC, 2006). Emissions related to forestry and other land use activities, especially biomass burning and organic soils degradation, are larger still, albeit somewhat constrainable via atmospheric measurements and inversion modeling (e.g., Friedlingstein *et al*, 2011). While the uncertainty consideration is unavoidable, a bottom-up database, global and with country-level detail, can and should be constructed. Indeed, just as the IEA database for fossil fuel emissions provides a reference for quality control, quality assurance analysis of national GHG inventories, the FAO Emissions database allows for more regular updates of AFOLU emissions worldwide, and represents a useful knowledge base for bridging some of the gaps and meet the science and policy needs highlighted above.

The latest global and regional GHG emissions estimates for AFOLU were published by the International Panel on Climate Change Fourth Assessment Report (AR4). FAO recently provided useful new data on livestock emissions and mitigation potentials (FAO, 2013a). The latter are based on life-cycle analysis, including emissions from food processing and transport, and are thus not directly comparable to those discussed in this report. According to IPCC, in 2005 GHG emissions from agriculture were 5.1-6.1 $GtCO_2eq\ yr^{-1}$, with another 7.5-8.5 $GtCO_2eq\ yr^{-1}$ related to forestry and other land use activities (FOLU)—the latter dominated by deforestation and forest degradation, peat fires and drainage. Compared to total estimated anthropogenic GHG emissions of about 50 $GtCO_2eq\ yr^{-1}$ in 2005, the AFOLU sector thus accounted for a third of total anthropogenic forcing (Smith *et al*., 2007).

FAO has developed and published in 2013 a new emissions database for the AFOLU sector (http://faostat3.fao.org/faostat-gateway/go/to/browse/G1/*/E), enabling the first global and regional update of AFOLU emissions since the AR4 and thus representing a major step forward in making AFOLU data more widely available to users worldwide (Tubiello *et al*, 2013).

This report presents a complete analysis of results of the updated and much expanded FAOSTAT Emissions database, providing a complete and coherent time-series of AFOLU emissions, as well as of emissions from energy use in agriculture including fisheries. The data are provided at country-level, based largely on FAOSTAT and Forest Resources Assessment (FRA) activity data communicated by countries and IPCC 2006 Tier 1 methodology (IPCC, 2006).

The exception for the source of activity data is for emission estimates that require geo-spatial information (via mapping and remote sensing analyses)—such as emissions from organic soils and biomass burning outside agriculture—which is typically not reported to FAO as a national statistic. In such cases, relevant activity data is estimated by FAO by aggregating at the national level geo-referenced information. IEA is used as a source of energy use data in the agriculture sectors including fisheries. The data are automatically updated as the underlying FAO activity data are published. Data are currently provided over the following reference periods: Agriculture, 1961-2011; Forestry and Other Land Use, 1990-2010; Energy use in agriculture, 1970-2010.

The FAOSTAT Emissions database has rapidly become a useful tool in support of member countries needs to identify, assess and report their GHG emissions from AFOLU. It was presented and discussed with representatives of nearly one hundred member countries through three regional workshops, held ahead of FAO Regional Commissions on Agricultural Statistics, and received formal endorsements from the Regional Commissions (APCAS, Vietnam, Oct 2012; IICA, Trinidad and Tobago, Jun 2013; AFCAS, Morocco, Dec 2013) (FAO, 2013b; 2014a). Furthermore, the FAOSTAT Emissions database is increasingly being used by FAO and other international agencies for in-country work, i.e., as a tool in both non-Annex I and Annex I countries, providing support to member countries' GHG Inventory needs related to UNFCCC, such as National Communications, Biennial Update Reports, and development of Nationally Appropriate Mitigation Actions (NAMAs).

Finally, the FAOSTAT Emissions data are integral part of the upcoming AFOLU emissions analysis of the IPCC Fifth Assessment Report (AR5), and thus contribute to the global knowledge base needed for identifying the role that agriculture, forestry and other land use activities can play under current and future international climate agreements towards limiting dangerous anthropogenic interference of the climate system.

PART I
METHODOLOGY

2. METHODS

2.1 General approach

Anthropogenic emissions of GHG gases can be estimated in isolation or via combinations of complementary approaches i) inventory-based, bottom-up accounting based on statistical compilation of activity data and regional emission factors; ii) atmospheric-based, top-down accounting using global mixing ratios and inversion modeling; and iii) process-based approaches, based on dynamic modeling of underlying processes, with specific rules for scaling-up in space and time.

In order to compile a global GHG emissions database with regional detail, all three approaches have been used. However, in order to address sectoral and regional contributions, with national level details, approaches under ii) are yet unsuitable. For national-level reporting of GHG emissions to the UNFCCC, IPCC guidelines (IPCC, 1997; 2000; 2003; 2006) provide a range of methodological approaches specified under i) and iii) above, i.e., from simple bottom-up methods (i.e., Tier 1) to more complex procedures often involving process modeling and rules for scaling-up in time and space (Tier 2 and Tier 3). More specifically, Tier 1 approaches provide for simple estimations, based on generalized emission factors and other parameter values that are specified either globally or regionally. Tier 2 approaches use country or region specific data. Tier 3 approaches involve models and/or inventory measurement systems.

FAO developed a global emissions database for agriculture, forestry and other land use (AFOLU) activities using Tier 1 IPCC 2006 methodology, with country level detail. Input activity data used were official national statistics from the FAOSTAT/FRA databases, complemented—for estimates of emissions from organic soils and biomass burning—by national aggregation of geo-spatial information obtained from global remote sensing and land cover/land use products created or endorsed by FAO.

The methodological strategy employed has several practical advantages. First, it allows the use of activity data (e.g., crop area, crop yield, livestock heads, land area, etc.) collected by member countries and officially communicated to FAO, typically *via* National Agriculture Statistical Offices and/or Ministries of Agriculture. This process results in an internationally approved, coherent data platform covering key information on inputs, production, costs and socio-economic indicators, trade and food balances, for a large range of agriculture and forestry products worldwide. Indeed, the FAOSTAT database is used widely in peer-reviewed literature, as a source of activity data for many AFOLU-related analyses, from global agriculture perspective studies to land-use change assessments and carbon cycle studies (i.e., Friedlingstein *et al.*, 2011). Secondly, the use of Tier 1 emission factors, while perhaps generating data with higher uncertainty level than data generated at higher Tiers, allows for the construction of a database where every country is treated equally, so that the estimated emissions data and their trends can be analyzed within a coherent framework. This is the same approach followed by the IEA database of GHG emissions from fossil fuel use, which is commonly employed by member countries to perform quality assurance/quality control (QA/QC) analysis of their GHG inventory data. By contrast, the UNFCCC GHG database, which provides GHG emissions data communicated by member countries, consists of a range of approaches at various Tiers.

The FAOSTAT Emissions database applies standard IPCC default equations for assessing bottom-up, country level GHG emissions using IPCC 2006 Guidelines and a Tier 1 (and IPCC Approach 1 for land-based emissions estimates) methodology (Tubiello *et al.*, 2013). It computes, for each sector:

$$Emission = EF*A \qquad (1)$$

where:

Emission = *GHG* emission of activity *A*;

A = activity data causing the emission; and

EF = emission factor per unit activity.

Specifically, IPCC Tier 1 emission factors for each emission category were assigned to countries in the database depending on geographic location or development status, following IPCC guidelines.

Uncertainty for agriculture categories

National level uncertainty is expressed for each emitting category by using the 95% confidence interval around emission estimates. To this end, default IPCC 2006 uncertainty values for activity data, parameters and emission factors were used, as well as default IPCC formulas for estimating error propagation of emissions within a country as well as at the global level. In general, emission estimates for agriculture at national level have uncertainties in the range 10-70% (Tubiello *et al.*, 2013).

The following sections provide a brief description of the methodology used in the estimation of GHG emissions analyzed herein. Much more detailed methodological information is provided in a separate guidelines report (FAO, 2014b, in preparation).

Mean Annual Growth Rates

For all GHG data discussed in this report, mean annual growth rates are computed directly in FAOSTAT, as the compound rate that would best fit –through least-square methods—the statistical data series over a specified time period, typically 2001-2010.

Regional aggregation

The GHG data in this report are presented with the following aggregations: global; by continent; and Annex I (AI)/Non-Annex I (NAI). Aggregation by continent follows the standard FAOSTAT classification. Annex I and Non-Annex I terminology refers to countries that are signatory parties to the United Nations Framework Convention on Climate Change (UNFCCC Convention); they aggregated according to UNFCCC classifications (http://unfccc.int/essential_background/glossary/items/3666.php).

2.2 Agriculture

Emissions from agriculture are computed for nearly 200 countries for the reference period 1961-2011, and are built in FAOSTAT for automatic updating of emissions as soon as new activity data from member countries are uploaded. The following sub-categories are part of the Emissions–Agriculture domain of the FAOSTAT Emissions database:

- Enteric Fermentation;
- Manure Management;
- Rice Cultivation;
- Synthetic Fertilizers;
- Manure applied to Soils;
- Manure left on Pasture;
- Crop Residues;
- Cultivation of Organic Soils;
- Burning – Savanna;
- Burning - Crop Residues;
- Energy Use in Agriculture.

For all sub-categories, GHG projections for 2030 and 2050 are computed with reference to projected increases in agricultural production made by the FAO Perspective Studies. To this end, projected 2030 and 2050 activity data (e.g., crop area; livestock numbers) are needed to estimate future GHG trends. The latter were computed by first setting a baseline value, defined as the 2005-2007 average of the corresponding FAOSTAT activity data, and then by applying to it the projected growth rate to 2030 and 2050 from the FAO perspective studies (FAO, 2006; Alexandratos and Bruinsma, 2012). The FAO perspective studies specify individual projections to 2030 and 2050 for some 140 countries. Projections of activity data for countries not specified in the FAO perspective studies were made by applying the projected growth rates of neighboring countries, consistently with the perspective studies' regional groupings.

2.2.1 Enteric Fermentation

Emissions from enteric fermentation consist of methane gas (CH_4) produced in digestive systems of ruminants and to a lesser extent of non-ruminants. The FAOSTAT data are computed at Tier 1, following IPCC 2006 Vol. 4, Ch. 10.

The emissions are estimated at country level, using formula (1) where:

A = activity data, representing number of livestock in heads;

EF = Tier 1, default IPCC emission factors, expressed in units of kg CH_4 head^{-1} yr^{1} as per IPCC, 2006: Vol. 4, Ch.10, Tab. 10.10-10.11.

Activity data cover the following animal categories: buffaloes, sheep, goats, camels, llamas, horses, mules, asses, pigs, dairy and non-dairy cattle.

2.2.2 Manure

Emissions from manure N applied to cropland as organic fertilizer, left on pasture by grazing animals, or processed in manure management systems, are computed at Tier 1 level, using statistics of animal numbers reported to FAOSTAT for estimating both nitrous oxide (N_2O) and CH_4 emission components. For N_2O emissions, a complex set of intermediate datasets was generated as per IPCC guidelines: manure N excretion rates; percent manure treated in different manure management systems; percent manure left on pasture; manure management system losses; and manure N application rates to cropland as organic fertilizer. The values of the intermediate datasets were animal and region specific. Indirect N_2O emissions related to volatilization and leaching processes of manure N management were also computed, following the relevant IPCC equation and emission factors. Estimates of CH_4 emissions from specific manure management systems require use of average annual temperature by country, this information was obtained from the FAO global agro-ecological zone database (FAO, 2012a).

2.2.3 Rice cultivation

Emissions from rice cultivation consist of CH_4 emitted by anaerobic decomposition of organic matter in paddy fields. The FAOSTAT data are computed at Tier 1 following IPCC, 1997: Vol. 3, Ch. 4 and IPCC, 2000, Ch. 4. Emissions are estimated at country level, using formula (1) where:

> *A* = Activity data, representing rice paddy annual harvested area in m^2 taken from FAOSTAT;
>
> *EF* = Tier 1, default IPCC emission factors, in g CH_4 $m^{-2}yr^{-1}$.

Activity data are disaggregated into irrigated, rain-fed and upland water regimes, using default IPCC percentages in IPCC, 1997: Vol. 3, Ch. 4, Tab. 4.11. Seasonally integrated EF values are those specified for key rice producing countries in the guidelines (IPCC, 1997: Vol. 3, Ch. 4, Tab. 4.13). Finally seasonally integrated EF values are modified by the application of a dimensionless scaling factor for water regime and a dimensionless correction factor for organic amendments. The scaling factors for rice paddy water regime (IPCC, 1997: Vol. 3, Ch. 4, Tab. 4.12) are in the range 0-1. Specifically for all countries a scaling factor of 0.7 is used for rain-fed rice and 0 for upland rice or dry conditions (IPCC, 2000: Tab. 3, page 403). The correction factor for organic amendments is the default value of 2 for all countries, corresponding to the assumption that 40% of farmers use organic amendments (IPCC, 2000: Tab. 3, page 403).

2.2.4 Synthetic Fertilizer

Emissions from synthetic fertilizers consist of direct and indirect N_2O emissions from nitrogen added to agricultural soils by farmers. Specifically, N_2O is produced by microbial processes of nitrification and de-nitrification taking place on the addition site (direct emissions), and after volatilization/re-deposition and leaching processes (indirect emissions). The emissions are estimated at Tier 1 following IPCC, 2006: Vol. 4, Ch. 11.

Direct emissions are estimated at country level, using formula (1): where:

> *A* = Activity data, representing amount of annual synthetic N applications in kg N yr^{-1}; taken from FAOSTAT.
>
> *EF* = Tier 1, default IPCC emission factor, expressed in kg N_2O-N / kg N yr^{-1} as per IPCC, 2006: Vol. 4, Ch.11, Tab. 11.1.

Indirect emissions are estimated at country level, using formula (1) where:

> *A* = Activity data, representing the amount of synthetic N applications that volatizes as NH_3 and NO_x and is lost through runoff and leaching in kg N yr^{-1};
>
> *EF* = Tier 1, default IPCC emission factor, expressed in kg N_2O-N / kg N yr^{-1} as per IPCC, 2006: Vol.4, Ch. 11, Tab. 11.3.

2.2.5 Crop residues

Emissions from crop residues consist of direct and indirect N_2O emissions from nitrogen in crop residues and forage/pasture renewal left on agricultural fields by farmers. The FAOSTAT data are estimated at Tier 1 following IPCC, 2006: Vol. 4, Ch. 2 and 11.

Direct and indirect emissions are estimated at country level using formula (1) in the same manner used for synthetic fertilizers.

Activity data are calculated from FAOSTAT crop yield and harvested area data and cover for the following crop categories: barley, beans-dry, maize, millet, oats, potatoes, rice-paddy, rye, sorghum, soybeans, and wheat, using IPCC, 2006: Vol.4, Ch. 11, Eq. 11.6 default crop values in Tab. 11.2. In a few cases where default parameters were not provided (N content of below-ground residues for rice and millet, and ratio of below-ground residues to above-ground biomass for millet, sorghum, rye, and beans-dry) the correspondent default values for crops with similar biophysical characteristics were used. The biomass N amount is corrected by the fraction of crop residue burnt on site—assumed to be 10% by area, following IPCC, 2000: Ch. 4, Section 4A.2.1.1—with specified combustion coefficients by crop, as per IPCC, 2006: Vol.4, Ch. 2, Tab. 2.6. All N in crop residues net of amount burnt is assumed to remain on the field, as per IPCC, 2006: Vol.4, Ch. 11, Eq. 11.6.

2.2.6 Cultivation of organic soils

Emissions included in agriculture from the cultivation of organic soils are those associated with nitrous oxide emissions following drainage of agriculture land (including cropland and grassland areas). The FAOSTAT data are computed at Tier 1 following IPCC, 2006: Vol. 4, Ch. 11. Emissions are estimated at pixel level (approximately one kilometre at the equator), using equation (1): where:

> *A* = Activity data, representing the annual area of cultivated organic soils;
>
> *EF* = Tier 1, default IPCC emission factors, expressed in kg N_2O-N / ha.

Input activity data are obtained through the stratification of three different global datasets:

- The Harmonized World Soil Database (FAO *et al.*, 2012), used to estimate the share of pixel area covered by histosols classes, identified as organic soils as per IPCC 2006 definitions;

- The Global Land Cover dataset, GLC2000 (EC-JRC, 2003), used to estimate the amount of cropland and grassland area in each pixel;
- The Gridded Livestock of the World for cattle and sheep (Wint and Robinson, 2007), used as an additional mask over grassland organic soils as a proxy for drained area (pixels with both non-zero grassland histosols area and livestock density>1 head/ha).

For the period 1990-present, the activity data reported in this sub-domain is a constant value, representing the mid-point of the two decades considered, i.e., the year 2000, or the reference year of the GLC2000 database.

The EF values are those specified in IPCC, 2006: Vol. 4, Ch. 11, Tab. 11.1. They were assigned at pixel level, in order to distinguish climate zones-specific values, as defined in IPCC, 2006: Vol. 4, Ch. 3, Annex 3A.5, using the climatic zones map from the Joint Research Centre of the European Commission (EC-JRC, 2010). Pixel-level estimates of both activity data and emissions were subsequently aggregated at country level using the FAO Global Administrative Unit Layers (GAUL) dataset.

2.2.7 Burning-Savanna

Emissions from burning of savanna consist of CH_4 and N_2O gases produced from the burning of biomass vegetation in the following five land cover types: *savanna, woody savanna, open shrubland, closed shrubland and grassland.* The FAOSTAT data are estimated at Tier 1 following IPCC, 2006, Vol. 4, Ch. 2, Eq. 2.27.

Emissions are estimated on a spatial grid at 0.25 degree resolution (approximately 25 km at the equator), using formula (1) where:

A = activity data, representing the total mass of fuel burned in each pixel, kg of dry matter;

EF = Tier 1, default IPCC emission factors, expressed in g CH_4 or g N_2O per kg of burned dry matter, as per IPCC, 2006: Vol. 4, Ch. 2, Tab. 2.5.

Total mass of fuel burned is computed by multiplying burned area by fuel biomass consumption values. Yearly composite burned area values are produced from monthly statistics of the Global Fire Emission Database v.4 (GFED4), based on MODIS remote-sensing data (Giglio ***et al***. 2013). The dataset provides burned area by land cover classes as identified by the MODIS Land Cover product (MCD12Q1) (Hansen ***et al***., 2000).

Fuel biomass consumption values are taken from IPCC, 2006: Vol.4, Ch. 2, Tab. 2.4. The different values were geographically allocated using the JRC Climate Zones map. Yearly values for the period 1990-1995 are set as a constant and estimated as the average of the period 1996-2012. Emission estimates made at pixel level are aggregated at country level using the FAO Global Administrative Unit Layers (GAUL) dataset.

2.2.8 Burning - Crop Residues

Emissions from burning crop residues consist of CH_4 and N_2O gases produced by the combustion of crop residues burnt on-site, net of removals for animal consumption, decay in the field, and use in other sectors (e.g., biofuel, domestic livestock feed, building materials, etc.). The FAOSTAT data are estimated at Tier 1 following IPCC, 2006: Vol. 4, Ch. 2 and 5.

The CH_4 and N_2O emissions are estimated at country level, using formula (1) where:

> *A* = activity data, representing the total amount of biomass burned, kg of dry matter;
>
> *EF* = Tier 1, default IPCC emission factors, expressed in gCH_4/kg of dry matter and gN_2O/kg of dry matter, as per IPCC, 2006: Vol. 4, Ch. 2, Tab. 2.5.

Activity data are calculated from FAOSTAT harvested area statistics and cover the following crops: wheat, maize, rice, and sugarcane. For the period 1961-present, harvested area is taken from FAOSTAT (domain Production/crops). Harvested area is used to estimate the amount of biomass burned using mean default crop values of mass of fuel available for combustion (M_B) and combustion factor (C_f) in IPCC, 2006: Vol.4, Ch. 2, Tab. 2.4. The mass is corrected by the fraction of crop residue burnt on-site—assumed to be 10%, following IPCC, 2000: Ch.4, Section 4A.2.1.1.

2.2.9 Energy use in agriculture

Emissions from energy use consist of carbon dioxide, methane and nitrous oxide gases associated with direct fuel burning and electricity generation for agriculture, including fisheries, comprising estimates for energy used in machinery, power irrigation, and fishing vessels. Data is computed at Tier 1, following the 2006 IPCC Guidelines for National GHG Inventories, Vol. 2, Ch. 2 and 3, and are relative to the period 1970-2010. Fuel emissions are estimated at country level, using equation (1), where:

> *A* = activity data, representing the amount or energy content of main fuel consumed in agriculture in kt yr^{-1}, TJ yr^{-1} or ktoe yr^{-1} for fuels, and GWh yr^{-1} for electricity;
>
> *EF* = emission factor, expressed as Gg of gas emitted per year per PJ (or kWh) of energy used.

Activity data are taken from the relevant UNSD and IEA databases of national energy use statistics; IEA country emission factors for electricity are applied.

2.3 Forestry and Other Land Use

Emissions by sources and removals by sinks (emissions/removals) from Forestry and Other Land Use activities (FOLU), also referred to as Land Use, Land Use Change and Forestry (LULUCF), are reported in the ***Emissions–Land Use*** domain of the FAOSTAT Emissions database. Net emissions (or net removals) are also reported, being defined as emissions by sources minus removals by sink.

Categories include:

- Forest Land
- Cropland
- Grassland
- Biomass Burning

For each of the land categories, FAOSTAT emission estimates do not include CO_2 emissions or removals from soil carbon management of mineral soils. These are generally a smaller component of total AFOLU emissions, as reported to UNFCCC.

2.3.1 Forest Land

Annual emissions/removals from Forest Land consist of net carbon stock change in the living biomass pool (aboveground and belowground biomass) associated with ***Forest*** and ***Net Forest Conversion*** to other land uses. They are computed at Tier 1 and Approach 1, with the stock difference method, following 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006). Activity data are taken from official country area and carbon stocks from the FAO Global Forest Resource Assessment (FRA) for the year 2010 (FAO, 2010). Estimates are available by country, with global coverage and relative to the period 1990-2010, with periodic updates linked to FRA publications**.**

Net CO_2 emissions/removals (*E/R*) are estimated at country level, using the formula:

$$E/R = A * CSCF * -44/12 / 1{,}000 \quad (2)$$

where:

A = Activity data, representing the forest area or the forest area net change, in ha;

CSCF = carbon loss change in the living biomass pool (above and belowground), expressed in t C/ha.

Data for the year 1990, 2000, 2005 and 2010, as provided by FRA, for categories ***Primary forest****,* ***Other naturally regenerated forest*** *and* ***Planted forest*** are linearly interpolated to compile, for each country, complete time series of areas for each category, for the period 1990-2010. FRA categories ***Primary forest*** and ***Other naturally regenerated forest*** were aggregated, while ***Planted forest*** were considered separately, to compute the following forest area components at year t:

a. Area of forest that was still forest in the previous year (area type SFA, or Stable Forest Area), computed as SFA = *Min (A(t), A(t-1));*

b. For ***Forest***, new net area converted to forest in the same year (area type NAD, or Net Area Difference), computed as: NAD = *Max(A(t)-A(t-1),0)*, thus including only positive net forest area change; or

c. For ***Net Forest Conversion***: net area loss converted from forest to other land uses (area type NAD), computed as: NAD = *Min(A(t)-A(t-1),0))*, thus including only negative net forest area change.

For each country, CSCF is computed from the carbon stock density in the living biomass (above and belowground) pool in year t, *b(t)*. The latter is obtained from data on per hectare carbon stocks taken directly from the FRA database for the years 1990, 2000, 2005 and 2010. These were linearly interpolated to compile, for each country, a complete time series of per hectare average carbon stock in the living biomass pool, *b(t)*, for the period 1990-2010. For countries for which FRA carbon stock data were not available, the relevant FRA regional carbon stock (table T2.21 of FRA) was applied.

For each year t, and each forest area type above, the CSCF is calculated as follows:

For ***Forest***:

i. CSCF(t, SFA) = Δ*b(t)* = *b(t)* – *b(t-1)*, for forest areas of type SFA;

ii. CSCF(t, NAD) = *b(t)*, for forest areas of type NAD.

The overall net carbon stock change factor at year t, CSCF(t), is computed as:

CSCF(t)=(CSCF(t, SFA)*SFA + CSCF(t, NAD)*NAD)/A

For ***Net Forest Conversion***:

i. CSCF(t, NAD) = b(t-***1)***, for forest areas of type NAD.

The overall net carbon stock change factor at year t, CSCF(t), is computed as:

CSCF(t) = CSCF(t, NAD)*NAD/A

For estimating uncertainty, it should be noted that estimates of living biomass carbon stocks is derived from information on growing stock and basic wood densities. According to FAO FRA 2005, growing stock data have uncertainties of ±8% for industrialized countries and ±30% for non-industrialized countries; basic wood density data have uncertainties of 10-40%. FAOSTAT estimates forest area uncertainties at ±10%.

2.3.2 Cropland

The emissions from cropland are those associated with the carbon dioxide following soil drainage due to the cultivation of organic soils for crop production. The FAOSTAT data are computed at Tier 1 following IPCC, 2006, Vol. 4, Ch. 11. The estimation of total area is the same as for the estimations of N_2O emissions form cultivation of organic soils for agriculture (see section 2.1.6). EF values for CO_2, are instead those specified in IPCC, 2006: Vol. 4, Ch. 11, Tab. 11.1. Similarly to procedures described for agriculture emissions of N_2O, climate-dependent EF values (IPCC, 2006: Vol. 4, Ch. 3, Annex 3A.5) were assigned at pixel level using the climatic zones map of the Joint Research Centre of the European Commission (EC-JRC, 2010). Pixel-level area and emissions estimates were aggregated at country level using the FAO Global Administrative Unit Layers (GAUL) dataset.

2.3.3 Grassland

The emissions from grassland are those associated with the carbon dioxide following soil drainage due to the cultivation of organic soils for livestock production. The methodology is described in sections 2.1.6 and 2.2.2.

2.3.4 Burning Biomass

Emissions consist gases produced by the burning of biomass. They are CH_4, N_2O, and, only in the case of organic soils, also CO_2 emissions. The following emission categories are included: ***'Humid Tropical Forest'***, ***'Other Forests'*** and ***'Organic Soils'***. ***Humid tropical forest*** is defined by aggregation of the following global ecological zones (GEZ) for forest data (FAO, 2012b): "Tropical Rainforest" and "Tropical moist deciduous forest". ***Other Forest*** contains the forest in the rest of GEZ. ***Organic soils*** are defined, similarly to other emission categories in the database, as the histosols class in the Harmonized World Soil Database. Emissions are estimated following IPCC, 2006, Vol. 4, Ch. 2, Eq. 2.27, in the same manner followed for the estimation of emissions from burning savanna. For forest, the GFED4 burned forest area is computed as an aggregate of the following MODIS land cover classes (MCD12Q1) (Hansen et al., 2000): ***evergreen needle-leaf, evergreen broadleaf, deciduous needle-leaf, deciduous broadleaf, and mixed forest.***

For ***Humid Tropical Forest***, burned area is obtained by overlapping the total GFED4 burned forest area data with the relevant FAO-FRA Global Ecological Zones. ***Other Forest*** burned area is obtained as the residual of total GFED4 burned forest area minus ***Humid Tropical Forest*** burned area.

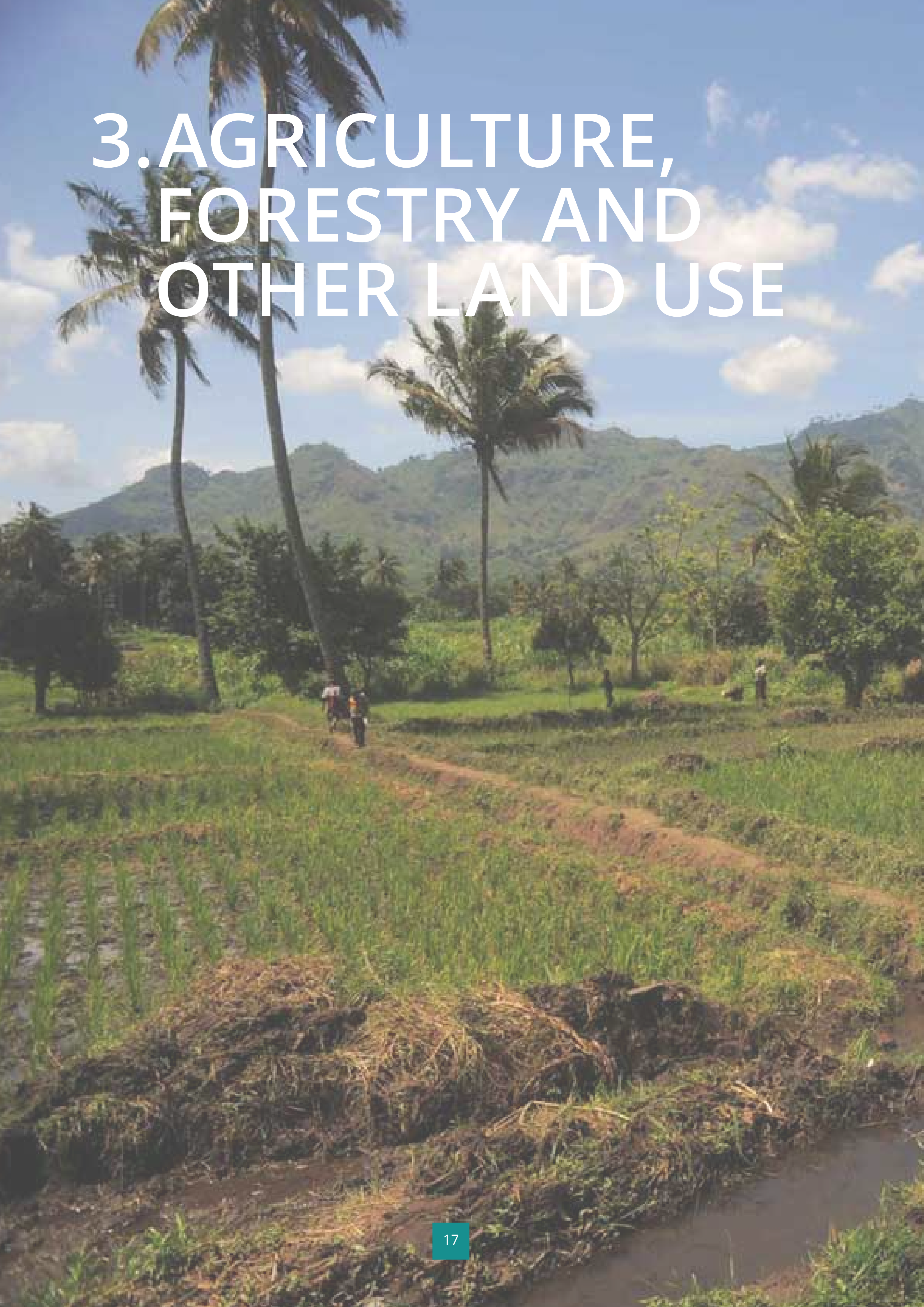
Organic soils burned area is obtained by overlapping total GFED4 burned area data with the histosols class information of the Harmonized World Soil Database, assuming even distribution of organic soils within the grid cell.

Fuel biomass consumption values are taken from IPCC, 2006: Vol.4, Ch. 2, Tab. 2.4, while EF values are taken from IPCC, 2006: Vol. 4, Ch. 2, Tab. 2.5. In both cases, climate-dependent values are geographically allocated using the JRC Climate Zones map.

For each item, pixel-level emissions were aggregated at country level using the FAO Global Administrative Unit Layers (GAUL) dataset. Since GFED4 data are not available before 1996, yearly emissions for the period 1990-1995 were estimated as the long-term average over 1996-2012.

PART II
RESULTS

3. AGRICULTURE, FORESTRY AND OTHER LAND USE



3.1 AFOLU Emissions and Removals: An Overview

Agriculture, Forestry and Other Land Use (AFOLU) activities generate greenhouse gas emissions by sources as well as removals by sinks, caused by the oxidation and fixation of organic matter via photosynthesis and complex microbial processes associated to human management and disturbance of ecosystems. They comprise non-CO_2 emissions by sources from agriculture, CO_2 and non-CO_2 emissions by sources from Forestry and Other Land Use (FOLU), and CO_2 removals by FOLU sinks. In the following sections, the term ***net emissions/ removals*** refers to emissions by sources minus removals by sinks.

1990-2010 Global trends

Over the period 1990-2010, total AFOLU net emissions increased 8%, from an average of 7,497 Mt CO_2 eq in the 1990s to an average of 8,103 Mt CO_2 eq in the 2000s (Fig. 3-1.a). They were the result of increases in agriculture emissions by 8%, i.e., from 4,613 to 4,984 Mt CO_2 eq; decreases in FOLU emissions by -14%, from 5,799 to 4,987 Mt CO_2 eq–due to a slow-down in net forest conversion; and decreases in FOLU removals by -36%, from -2,915 to -1,868 Mt CO_2 eq (Fig. 3-1.b).

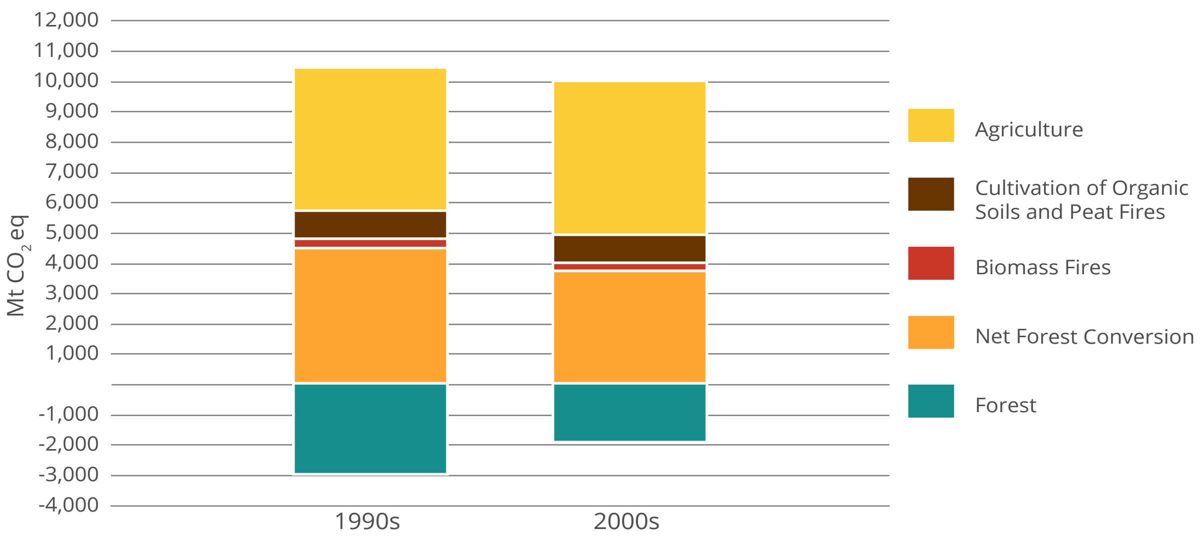


FIGURE 3-1a Historical trends in AFOLU, 1990-2010: Decadal averages

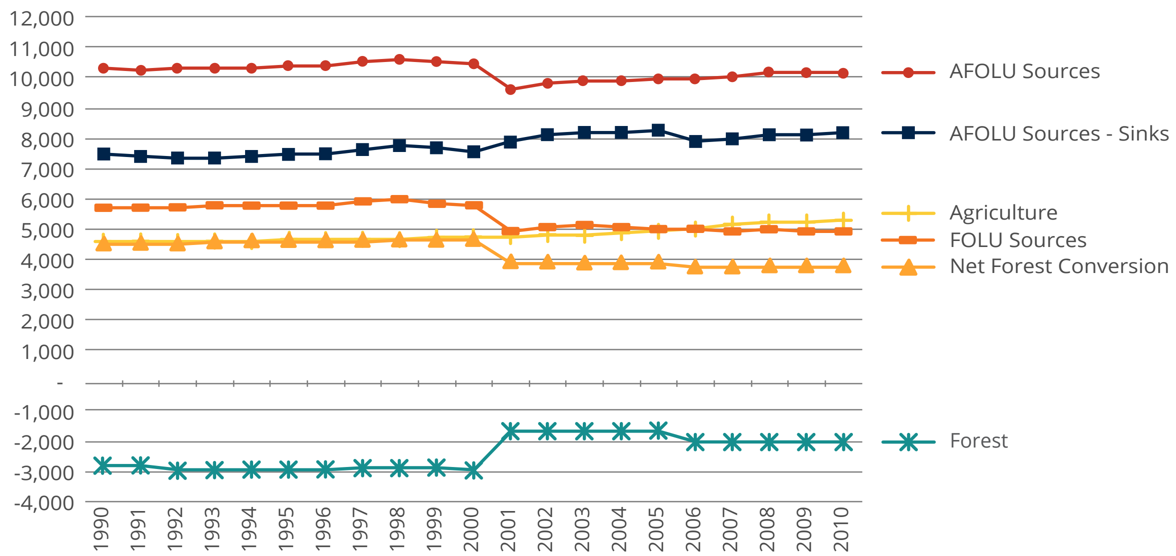


FIGURE 3-1b Historical trends in AFOLU, 1990-2010: Annual emissions

2001-2010 Trends: Sub-sectors

The share of agriculture emissions to total AFOLU net emissions remained constant over 1990-2010, at about 62%. By contrast, the share of agriculture to AFOLU emissions by sources (i.e., excluding FOLU sinks) increased, from 44% in the 1990s to 50% in the 2000s (Fig. 3-2).

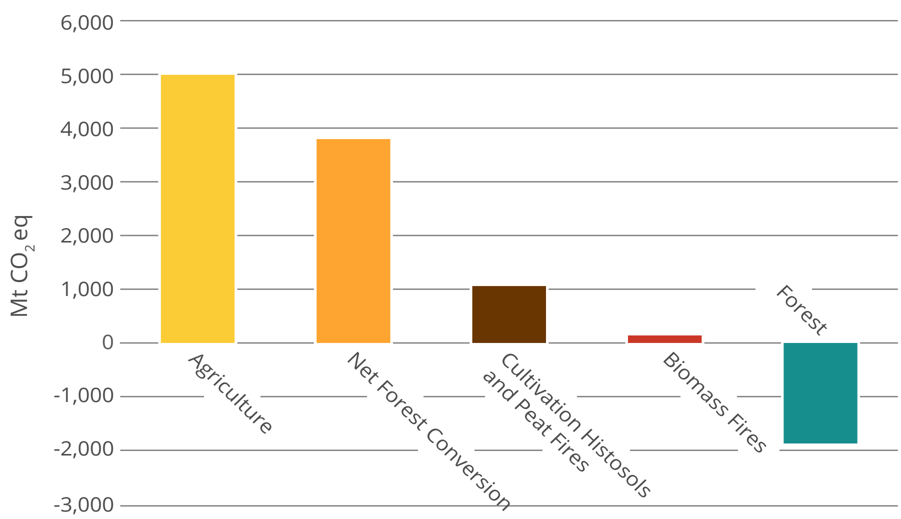


FIGURE 3-2 AFOLU sources and sinks by sub-sector, 2001-2010

For the period 2001-2010, the largest emission source was agriculture (50%), followed by net forest conversion (38%), peat degradation (i.e., cultivation of organic soils and peat fires) (11%) and biomass fires (1%). Forest (forest management and afforestation) contributed 100% of FOLU removals by sink, and represented a 20% offset of total AFOLU emissions by source (Tab. 3-1).

TABLE 3-1 AFOLU emissions by decade and in 2010 (Mt CO_2 eq).

Sector	Emissions	1990s	2000s	2010
Agriculture	Sources	4,613	4,984	5,258
LULUCF	Sources	5,799	4,987	4,941
Net Forest Conv.		*4,568*	*3,789*	*3,738*
Peat Degradation		*1,055*	*1,058*	*1,021*
Biomass Fires		*176*	*140*	*182*
LULUCF	Sinks	-2,915	-1,868	-2,050
Forest Land		*-2,915*	*-1,868*	*-2,050*
AFOLU	Sources	10,412	9,971	10,199
AFOLU	Net	7,497	8,103	8,149

AFOLU share to total emissions

Average total anthropogenic emissions by sources were about 44,000 Mt CO_2 eq in 2001-2010. AFOLU emissions by sources contributed 21% (agriculture and combined FOLU sources each contributed 11%). FOLU removals by sinks provided a 4% offset (Tubiello *et al,* 2014).

3.2 Agriculture Emissions: An Overview

Greenhouse gas emissions from agriculture consist of non-CO_2 gases, specifically methane, CH_4, and nitrous oxide, N_2O, produced from biological activities linked to bacterial decomposition processes in cropland and grassland soils and in livestock's digestive systems. Emissions include processes linked to enteric fermentation, manure management, rice cultivation, synthetic fertilizers, manure left on pasture, manure applied to soils, cultivation of organic soils, crop residues decay, prescribed burning of savannahs and field burning of crop residues.

2011

In 2011 total annual emissions from agriculture were 5,335 Mt CO_2 eq, the highest level in history, and almost 9% higher than the decadal average 2001-2010. Emissions in non-Annex I countries represented three-fourths of the total (Fig. 3-3).

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased 14%, from 4,684 to 5,335 Mt CO_2 eq. Growth took place almost entirely in non-Annex I (**NAI**) countries (i.e., 21%, from 3,356 to 4,048 Mt CO_2 eq), while it decreased in Annex I (**AI**) countries by -3%. From 1990 to 2011, emissions decreased in Annex I countries by -20%, while the increased by 37% in non-Annex I countries. In 2011, emissions in Annex I countries climbed up for the first time since 1990, to over 1,280 Mt CO_2 eq, the highest level since 2003.

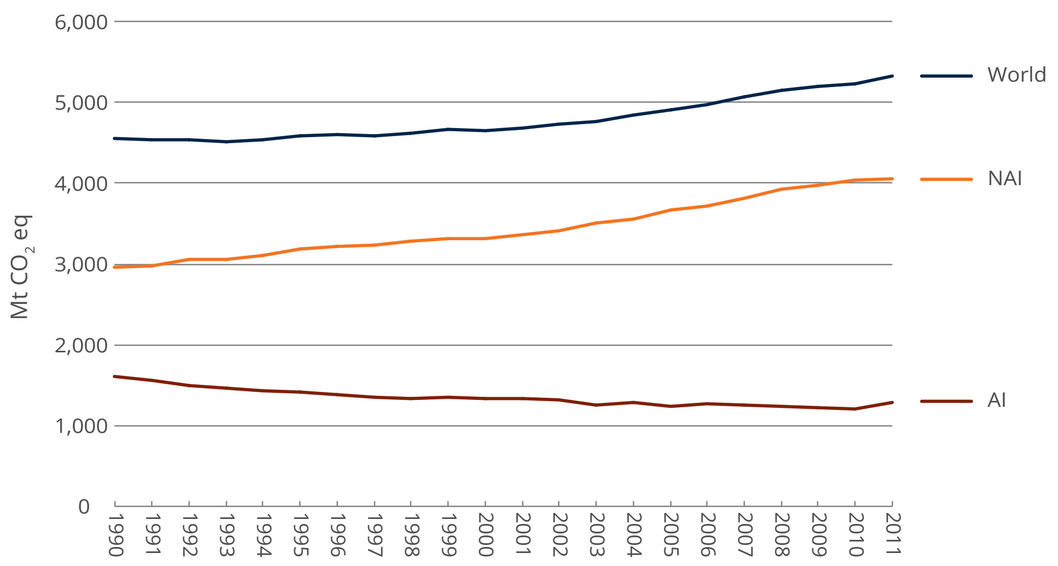


FIGURE 3-3 Historical trends in agriculture emissions, 1990-2011

2001-2011 Trends: by Continent

Asia (44%) and the Americas (26%) were the largest contributors to global emissions, followed by Africa (15%) and Europe (12%) (Fig. 3-4.a). Mean annual emissions growth rates over the same period were largest in Asia (2.3% yr^{-1}) and Africa (2.0% yr^{-1}), while they were negative in Oceania (-2.0% yr^{-1}) (Fig. 3-4.b). Africa overtook Europe as the third largest emitter since the year 2000.

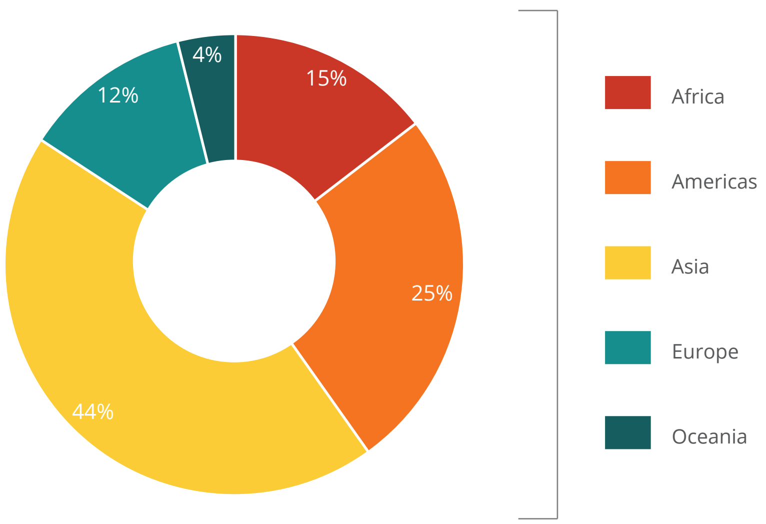


FIGURE 3-4a Agriculture, 2001-2011: emissions by continent

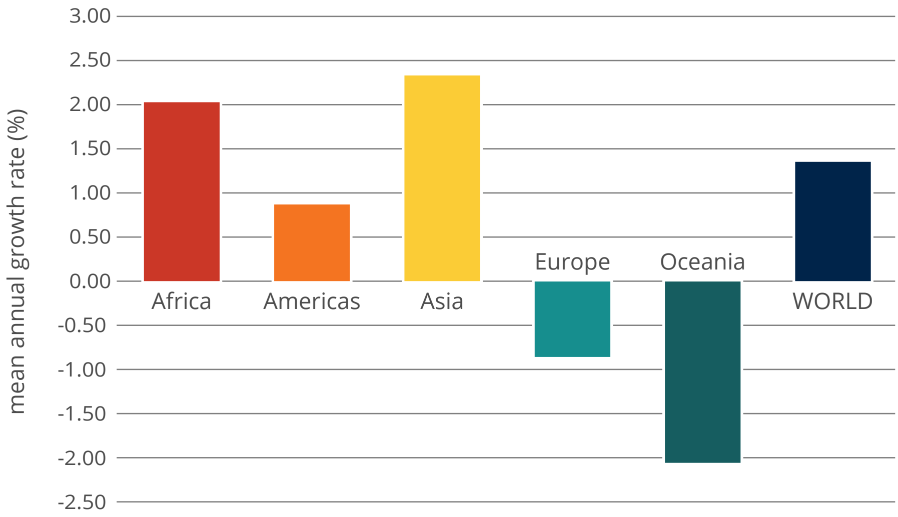


FIGURE 3-4b Agriculture, 2001-2011: annual growth rates by continent

2001-2011 Trends: Sub-sectors

Emissions from ***enteric fermentation*** were the greatest contributor to agricultural emissions (40%), followed by manure left on pasture (16%), synthetic fertilizers (13%), rice cultivation (10%), manure management (7%) and burning of savanna (5%) (Fig. 3-5).

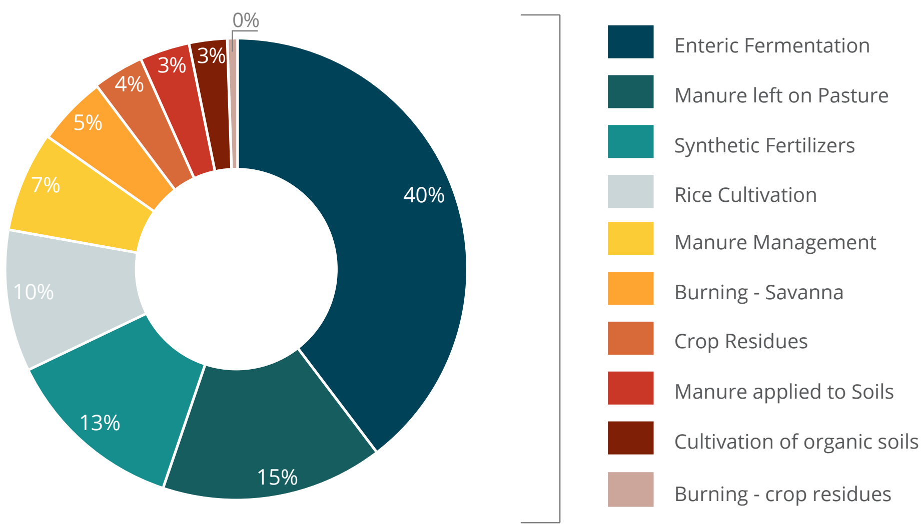


FIGURE 3-5 Agriculture emissions by sub-sector, 2001-2011

TABLE 3-2 Agriculture emissions by decade and in 2011 (Mt CO_2 eq).

Countries	1990s	2000s	2011
AI	1,439	1,275	1,287
NAI	3,138	3,625	4,048
World	4,578	4,900	5,335

Projections: 2030 and 2050

With respect to the average 2001-2010, global agricultural emissions are projected to increase in 2030 and 2050 by 18% and 30%, respectively, reaching more than 6,300 Mt CO_2 eq in 2050.

3.3 Forestry and Other Land Use Emissions and Removals: An Overview

Greenhouse gas emissions and removals in FOLU consist mainly of CO_2 linked to the oxidation and fixation of organic matter following human disturbance. Non-CO_2 emissions are linked to loss by fire of biomass and organic soils. The estimated emissions data include processes on ***forest land*** (*net forest conversion and forest*), ***cropland*** and ***grassland***, the latter two dominated by emissions from drainage and fires on organic soils.

2010

In 2010, world total annual GHG net emissions from FOLU were 2,816 Mt CO_2 eq. This level is 8% lower than the decadal average 2001-2010. The FOLU net emissions were the result of removals by sink in Annex I countries of -860 Mt CO_2 eq, combined with emissions by source of 3,676 Mt CO_2 eq. in non-Annex I countries (Tab. 3-3).

TABLE 3-3 FOLU emissions by decade and in 2010 (Mt CO_2 eq)

Countries	1990s	2000s	2010
AI	-428	-636	-860
NAI	3,241	3,673	3,676
World	2,812	3,038	2,816

2001-2010 Trends: Global

Over the period 2001-2010, annual net emissions decreased by -10%, from 3,133 to 2,816 Mt CO_2 eq. Just as in 2010, this was the result of a growing net sink in Annex I countries (i.e., +54%, from -557 to -860 Mt CO_2eq), combined with a stable though large net source from non-Annex I countries, from 3,690 to 3,676 Mt CO_2 eq. From 1990 to 2010, the net sink in Annex I countries increased by 157%, while the net source in non-Annex I countries increased only slightly, by +0.7%.

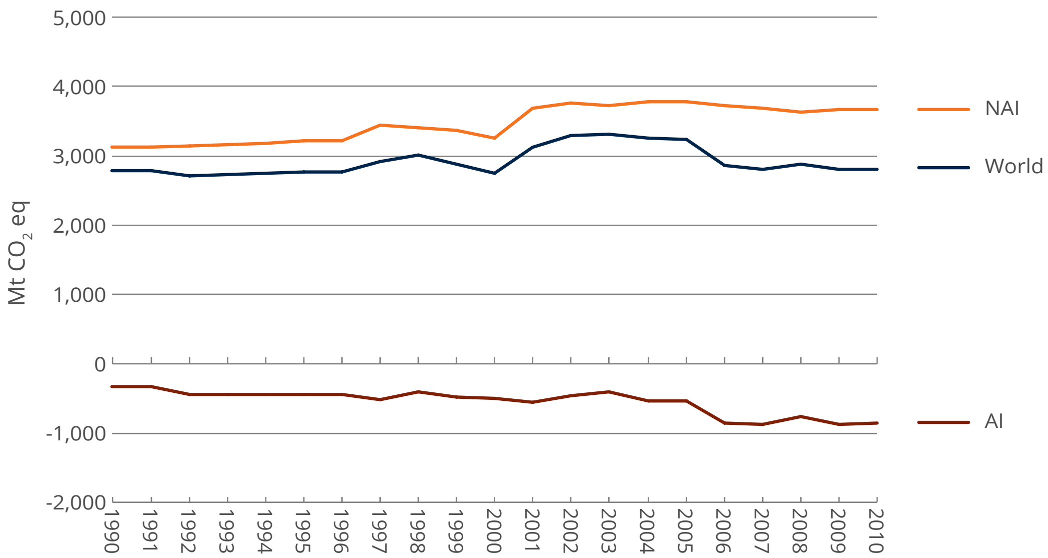


FIGURE 3-6 Historical trends in FOLU emissions/removals, 1990-2010

2001-2010 Trends: by Continent

At regional level, all continents except for Europe (offsetting about 10% of global FOLU emissions by source) were emission sources, dominated by the Americas (37%), Africa (28%) and Asia (22%) (Fig. 3-7).

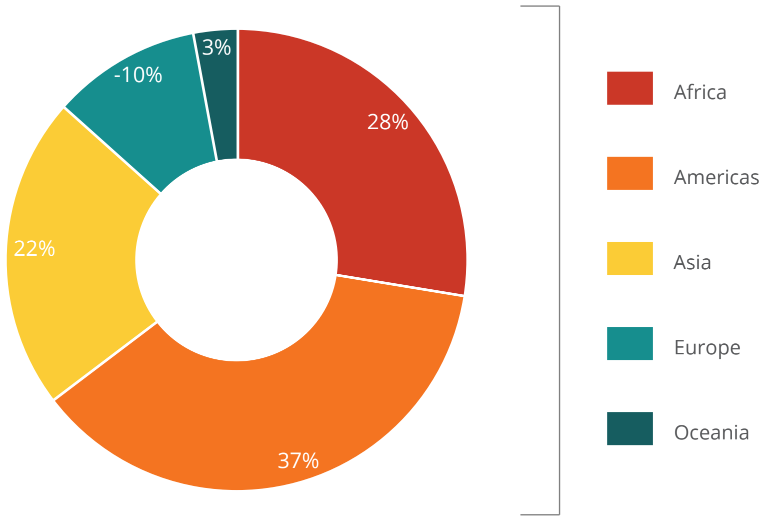


FIGURE 3-7a FOLU, 2001-2011: emissions/removals by continent

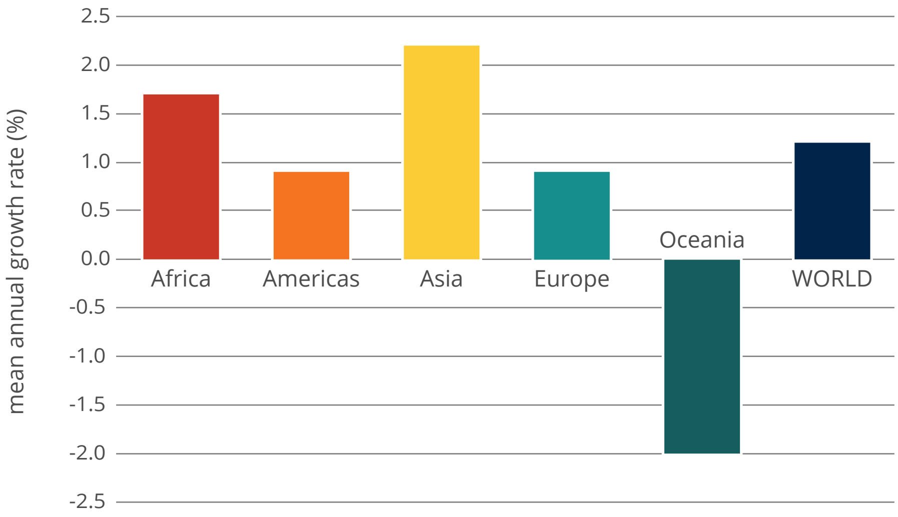


FIGURE 3-7b FOLU, 2001-2011: annual growth rates by continent

2001-2010 Trends: Sub-sectors

All land use categories were globally net emission sources. The largest was forest land (63%), followed by cropland (25%) and grassland (11%) (Fig. 3-8). Non-CO_2 emissions from burning biomass (forest and peat fires) contributed 1% to the total.

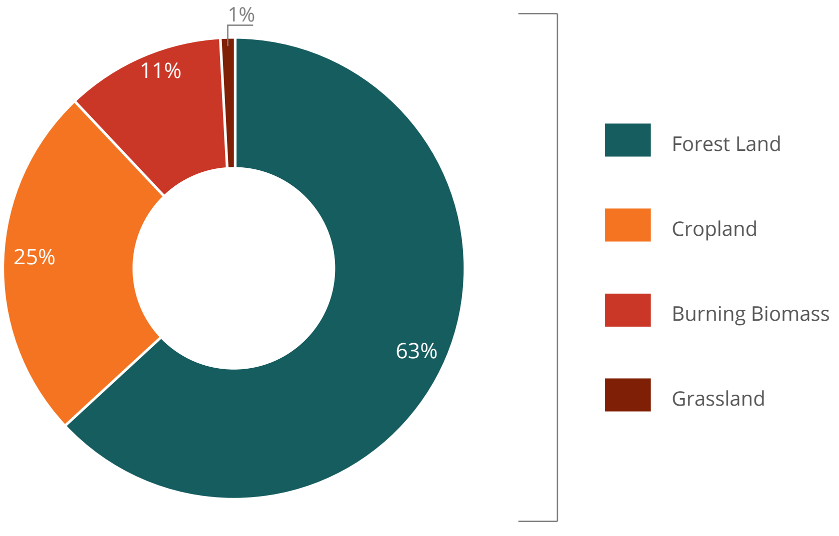


FIGURE 3-8 FOLU emissions by sub-sector, 2001-2010

4. AGRICULTURE

4.1 Enteric Fermentation

Greenhouse gas emissions from enteric fermentation consist of methane, CH_4, produced in digestive systems of ruminants and to a lesser extent of non-ruminants. Estimates include emissions by cattle, buffaloes, sheep, goats, camels, llamas, horses, mules, asses and swine.

2011

In 2011, world total annual GHG emissions from enteric fermentation were 2,071 Mt CO_2 eq, about 40% of total emissions from agriculture in the same year. Emissions in non-Annex I countries represented more than three-fourths of the total –although on a per-animal basis they continue to be larger in Annex I countries.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased 11%, from 1,858 Mt CO_2 eq to 2,071 Mt CO_2 eq. Emissions growth took place almost entirely in non-Annex I countries (i.e., 19%, from 1,355 Mt CO_2 eq to 1,613 Mt CO_2 eq), while it decreased in Annex I countries by 9%. From 1990 to 2011, emissions decreased in Annex I countries by -32%, while they increased by 35% in non-Annex I countries (Fig. 4-1).

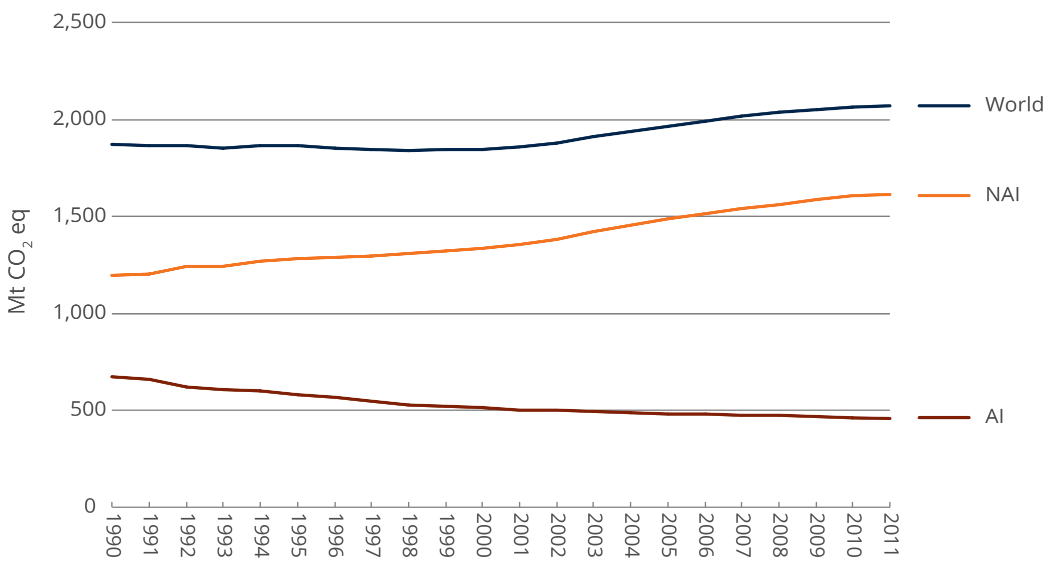


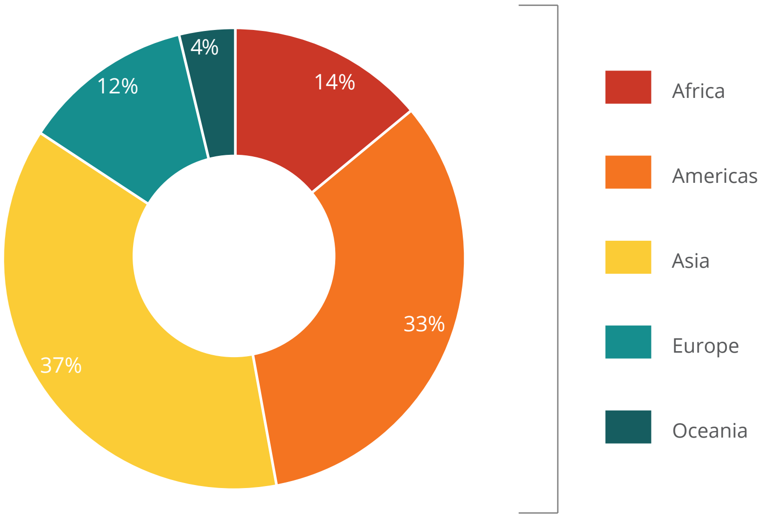
FIGURE 4-1 Historical trends in emissions from enteric fermentation, 1990-2011

TABLE 4-1 Enteric fermentation emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	591	487	458
NAI	1,266	1,463	1,613
World	1,857	1,950	2,071

2001-2011 Trends: by Continent

Asia and the Americas were the largest emitters (37% and 33% respectively), followed by Africa (14%) and Europe (12%) (Fig. 4-2.a). Average annual emissions growth rates over the same period were largest in Africa (2.7% yr^{-1}) and Asia (2.0% yr^{-1}), while they were negative in Europe (-1.6% yr^{-1}) and Oceania (-1.0% yr^{-1}) (Fig. 4-2.b). Africa overtook Europe as the third largest emitter in 2001-2011 with respect to 1990-2001.



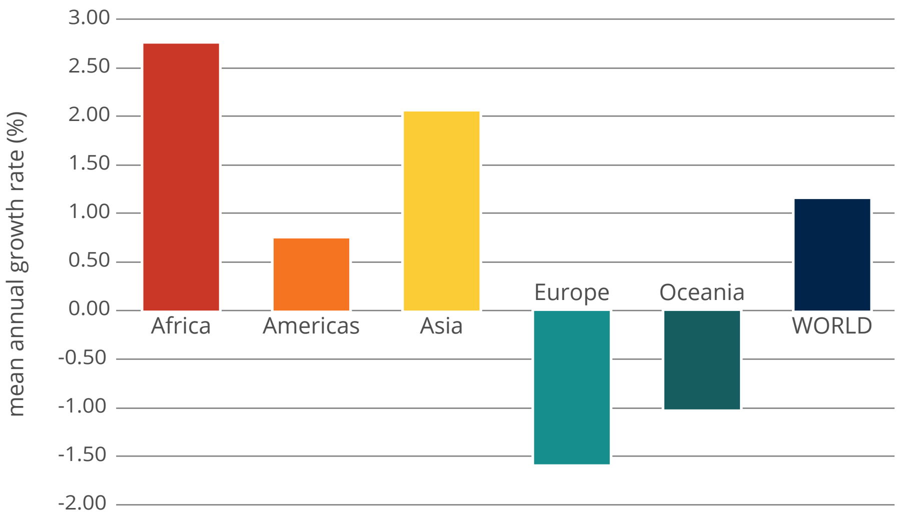


FIGURE 4-2 Enteric Fermentation, 2001-2011: (a) emissions and (b) annual growth rates, by continent

2001-2011 Trends: Sub-sectors

Emissions of enteric fermentation were dominated by cattle, contributing 74% of all enteric fermentation (55% non-dairy cattle; 19% dairy cattle), followed by buffaloes (11%), sheep (7%) and goats (5%) (Fig. 4-3).

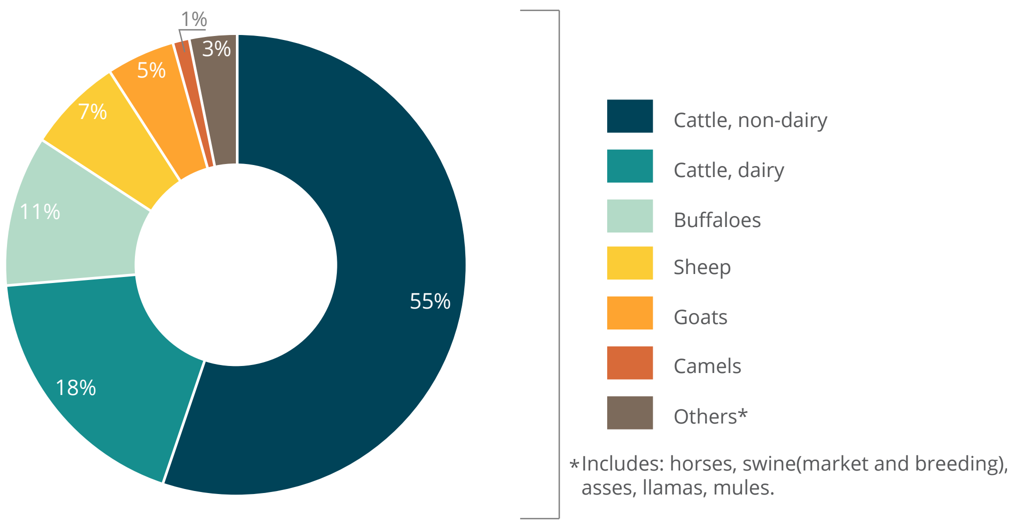


FIGURE 4-3 Enteric fermentation by sub-sector, 2001-2011

Projections: 2030 and 2050

With respect to average 2000's levels, global emissions from enteric fermentation are projected to increase by 19% and 32% in 2030 and 2050, respectively, reaching more than 2,500 Mt CO_2 eq in 2050.

4.2 Manure Management

Greenhouse gas emissions from manure management consist of methane (CH_4) and nitrous oxide (N_2O) from aerobic and anaerobic decomposition processes. Estimates include emissions by cattle, buffaloes, sheep, goats, camels, llamas, horses, mules, asses, ducks, turkeys, chickens and swine.

2011

In 2011, world total annual GHG emissions from manure management were 361 Mt CO_2 eq, about 7% of total emissions from agriculture in the same year. Emissions in non-Annex I countries represented 55% of the total.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased about 10%, from 329 to 362 Mt CO_2 eq. Emissions growth took place almost entirely in non-Annex I countries (i.e., 22% from 163 to 199 Mt CO_2 eq), while it decreased in Annex I countries by -2%. From 1990 to 2011, emissions decreased in Annex I countries by -17%, but increased by 43% in non-Annex I countries (Fig. 4-4).

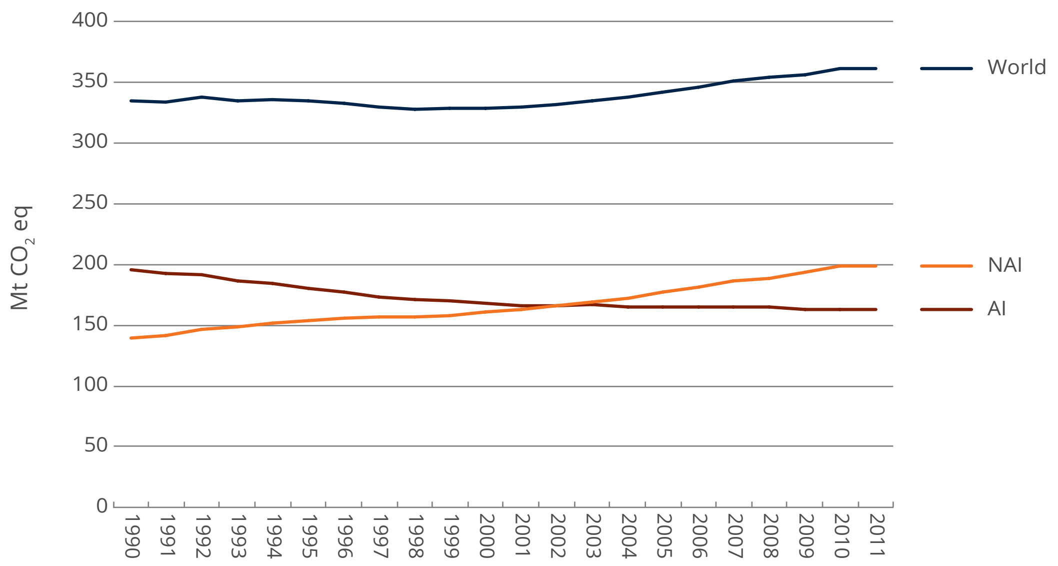


FIGURE 4-4 Historical trends in emissions from manure management, 1990-2011

2001-2011 Trends: by Continent

Asia and the Europe were the largest emitters (43% and 27% respectively), followed by Americas (22%) and Africa (5%) (Fig. 4-5.a). Average annual emissions growth rates over the same period were largest in Africa (3.1% yr^{-1}) and Asia (2.1% yr^{-1}), while they were negative in Europe (-0.6% yr^{-1}) and Oceania (-0.2% yr^{-1}) (Fig. 4-5.b).

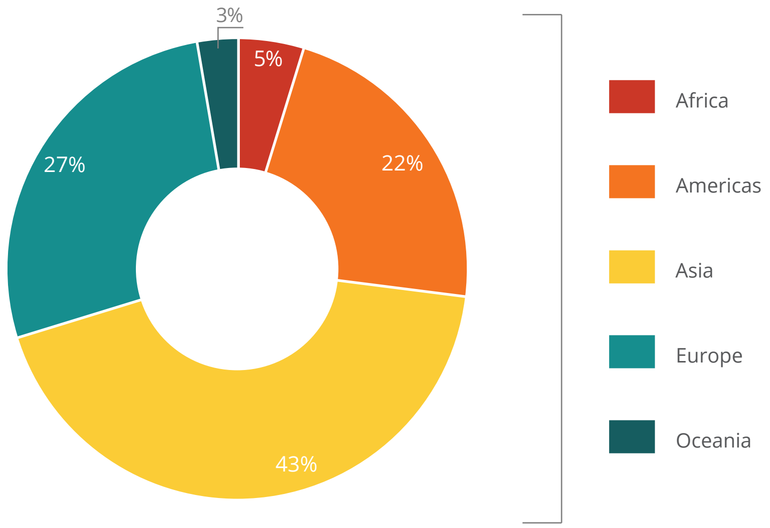


FIGURE 4-5a Manure Management, 2001-2011: emissions by continent

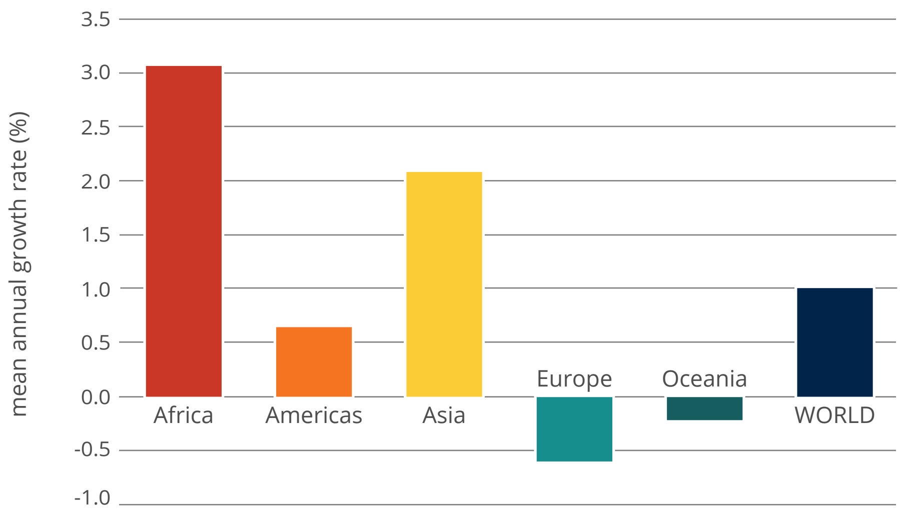


FIGURE 4-5b Manure Management, 2001-2011: annual growth rates, by continent

2001-2011 Trends: Sub-sectors

Emissions of manure management were dominated by cattle, responsible for half of the total (31% non-dairy cattle; 19% dairy cattle), followed by swine (34%) and buffaloes (9%) (Fig. 4-6).

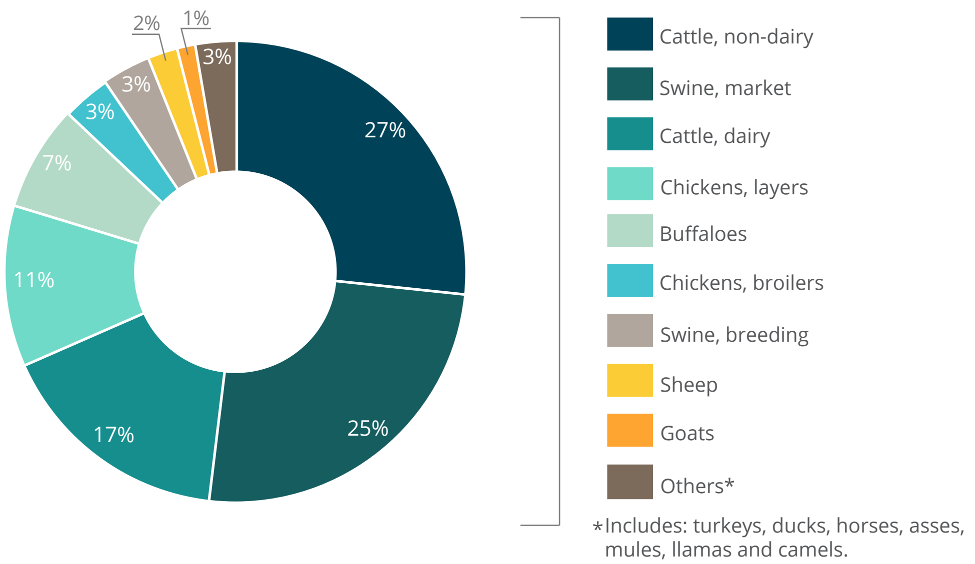


FIGURE 4-6 Manure management by sub-sector, for the period 2001-2011

TABLE 4-2 Manure management emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	182	165	163
NAI	151	176	199
World	333	341	362

Projections: 2030 and 2050

With respect to average 2000's levels, global emissions from manure management are projected to increase by 6% and 47% in 2030 and 2050, respectively, reaching more than 452 Mt CO_2 eq in 2050.

4.3 Rice Cultivation

Greenhouse gas emissions from rice cultivation consist of methane, CH_4, produced from the anaerobic decomposition of organic matter in paddy fields.

2011

In 2011, world total annual GHG emissions from rice cultivation were 522 Mt CO_2 eq, about 10% of total emissions from agriculture in the same year. Emissions in non-Annex I countries represented more than 95% of the total, in direct relation to shares of cultivated paddy rice area.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased by 8%, from 483 to 522 Mt CO_2 eq. Emissions growth took place almost entirely in non-Annex I countries (i.e., 9%, from 459 to 500 Mt CO_2 eq). From 1990 to 2011, emissions decreased in Annex I countries by -15%, while they increased by 14% in non-Annex I countries (Fig. 4-7).

TABLE 4-3 Rice cultivation emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	25	23	23
NAI	450	467	500
World	475	490	523

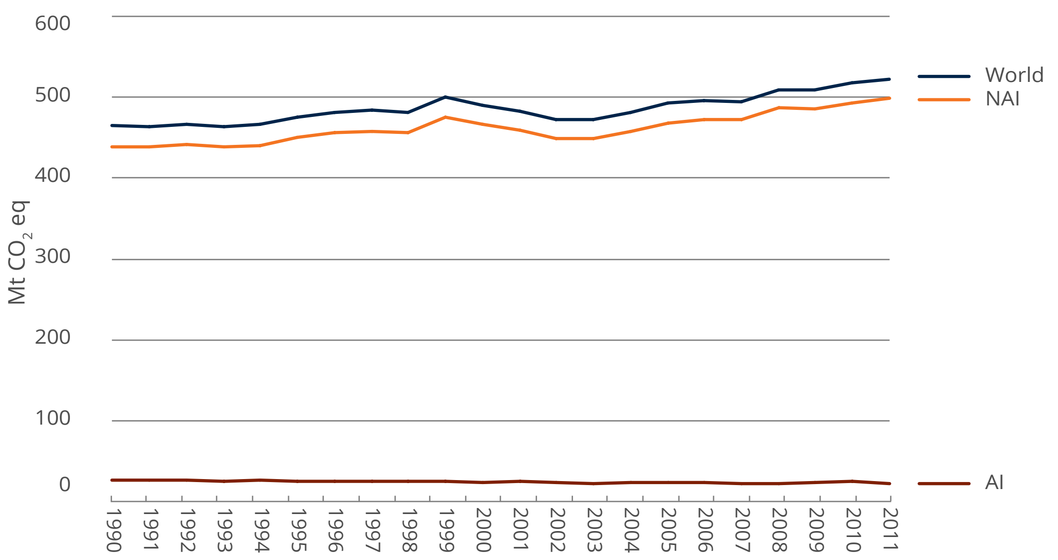


FIGURE 4-7 Historical trends in emissions from rice cultivation, 1990-2011

2001-2011 Trends: by Continent

During the period 2001-2011 Asia was the largest contributor (89%), followed by Africa (5%), the Americas (5%) and Europe (1%) (Fig. 4-8.a). Average annual emissions growth rates over the same period were largest in Africa (3.1% yr^{-1}), followed by Europe (2.0% yr^{-1}) and Asia (0.9% yr^{-1}), while they remained stable in the Americas and drastically decreased in Oceania (-18.3% yr^{-1}) (Fig. 4-8.b). Africa overtook the Americas as the third largest emitter in 2011.

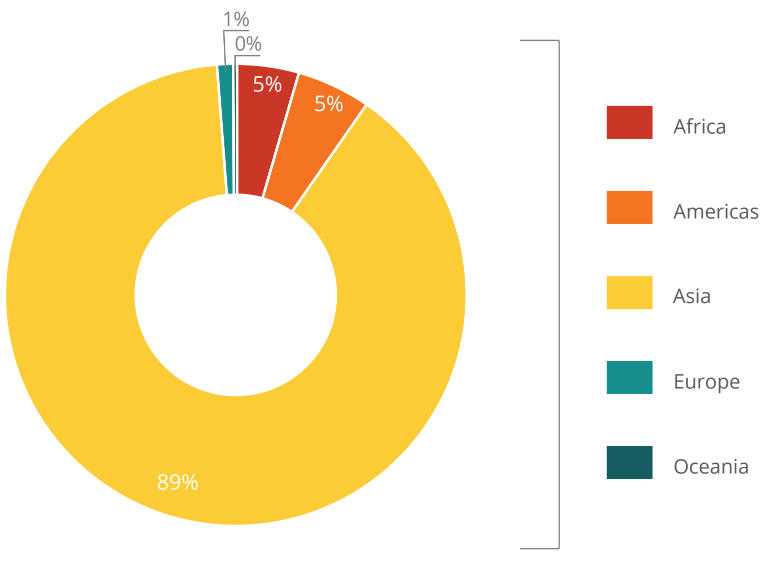


FIGURE 4-8a Rice cultivation, 2001-2011: emissions by continent

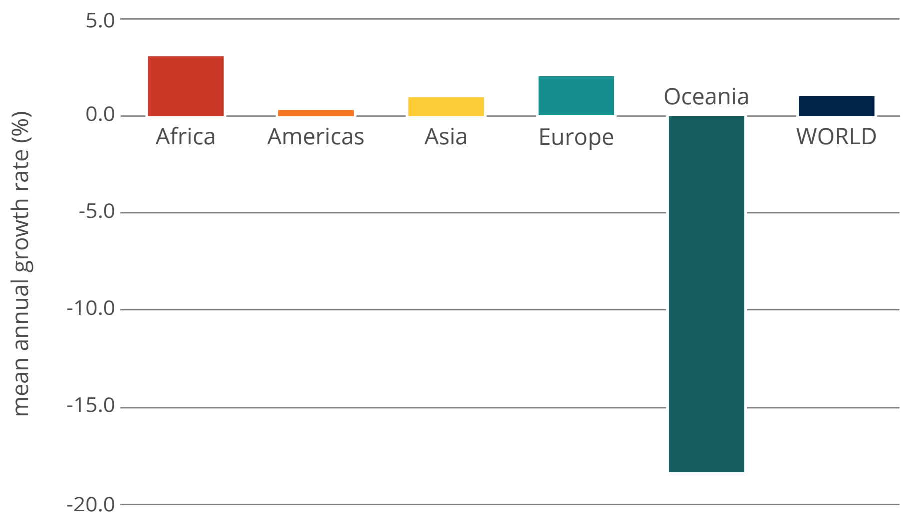


FIGURE 4-8b Rice cultivation, 2001-2011: annual growth rates by continent

Projections: 2030 and 2050

With respect to average 2000's levels, global emissions from rice cultivation are projected to increase by 7% and 6% in 2030 and 2050, respectively, reaching more than 500 Mt CO_2 eq in 2050.

4.4 Agricultural Soils

Greenhouse gas emissions from agricultural soils consist of methane and nitrous oxide produced in the following sub-sectors: synthetic fertilizers, manure applied to soils, manure left on pasture, crop residues, cultivation of organic soils and synthetic fertilizers.

4.4.1 Synthetic fertilizers

Greenhouse gas emissions from synthetic fertilizers consist of nitrous oxide from synthetic nitrogen added to managed soils.

2011

In 2011, world total annual emissions from synthetic fertilizers were 725 Mt CO_2 eq, about 14% of total emissions from agriculture in the same year. Emissions in non-Annex I countries represented more than 70% of the total.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased 37%, from 530 to 725 Mt CO_2 eq. Emissions growth took place almost entirely in non-Annex I countries (i.e., 53%, from 345 to 528 Mt CO_2 eq), with limited growth in Annex I countries (6%). From 1990 to 2011, emissions decreased in Annex I countries by -14%, while in non-Annex I countries increased by nearly 100%.

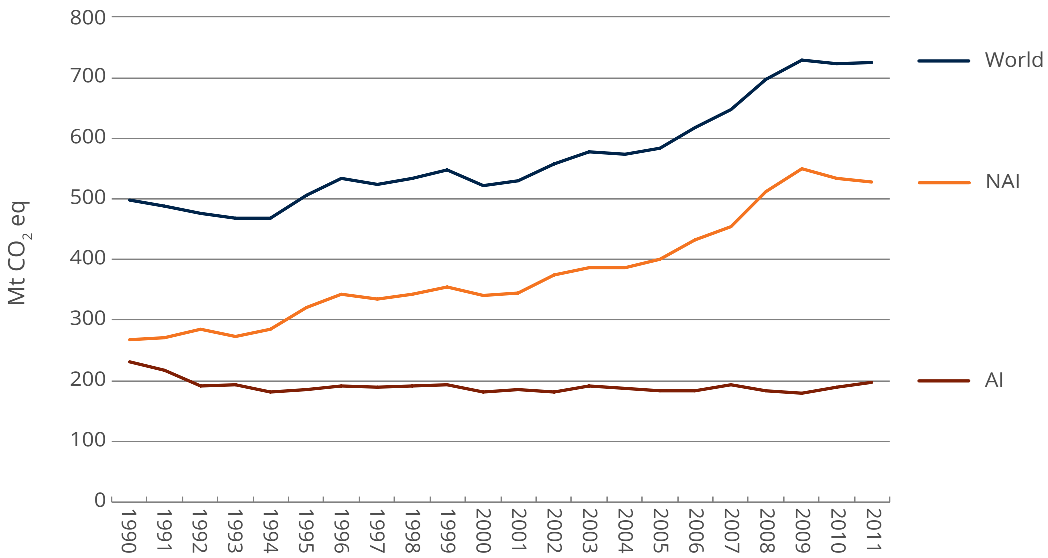


FIGURE 4-9 Historical trends in emissions from synthetic fertilizers, 1990-2011.

2001-2011 Trends: by Continent

Asia was the largest contributor to the total (63%), followed by the Americas (20%) and Europe (13%) (Fig. 4-10.a). Africa was a minor contributor (3%). Annual growth rates over the same period were largest in Asia (5% yr^{-1}), with good growth in the Americas and Africa (1.8% yr^{-1}), while they were near zero in Europe and negative in Oceania (-0.9% yr^{-1}) (Fig. 4-10.b).

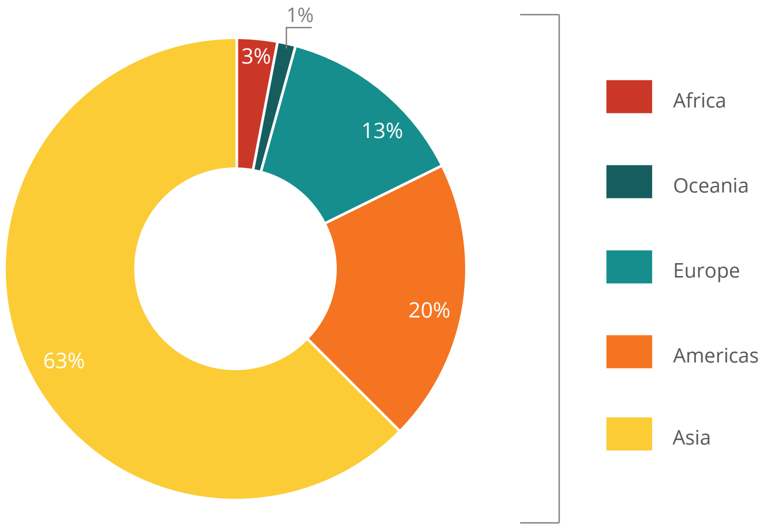


FIGURE 4-10a Synthetic fertilizers, 2001-2011: emissions by continent.

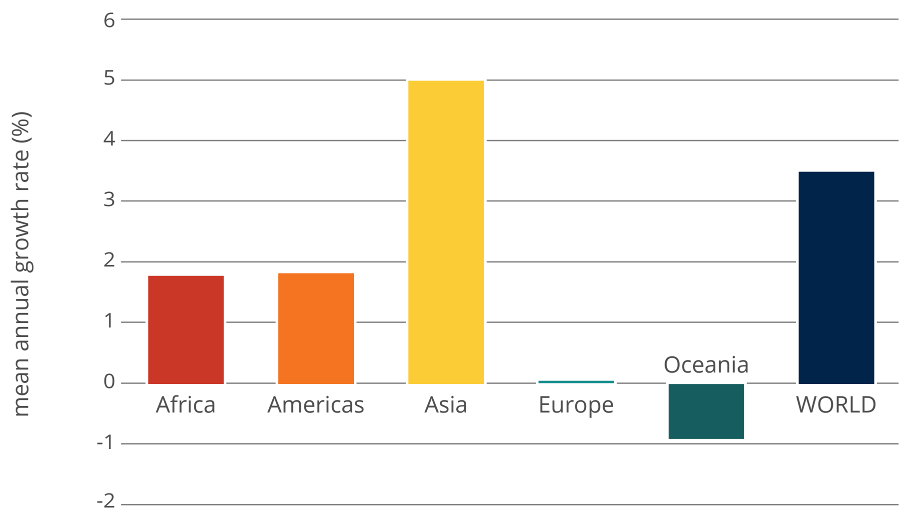


FIGURE 4-10b Synthetic fertilizers, 2001-2011: annual growth rates by continent.

TABLE 4-4 Synthetic fertilizers emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	197	185	197
NAI	308	418	529
World	504	604	725

Projections: 2030 and 2050

With respect to the 2000s average levels, global emissions from synthetic fertilisers are projected to increase in 2030 and 2050 by 32% and by 48%, respectively, reaching nearly 900 Mt CO_2 eq in 2050. Most of the growth is expected in non-Annex I countries, with increases of over 65% in 2050.

4.4.2 Manure applied to soils

Greenhouse gas emissions from manure applied to soils consist of nitrous oxide, N_2O, produced from nitrogen additions. Estimates of emissions include manure from cattle, buffaloes, sheep, goats, camels, llamas, horses, mules, asses, ducks, turkeys, chickens and swine.

2011

In 2011, world total annual GHG emissions from manure applied to soils were 1845 Mt CO_2 eq, about 4% of total emissions from agriculture in the same year. Emissions in non-Annex I countries represented more than 60% of the total.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased more than 12%, from 164 to 185 Mt CO_2 eq. This was the result of strong growth in non-Annex I countries (i.e., 27%, from 91 to 115 Mt CO_2 eq) and a consistent decrease in Annex I countries (-5%). From 1990 to 2011, emissions decreased in Annex I countries by -31%, but increased significantly in non-Annex I countries, by 58% (Fig. 4-11).

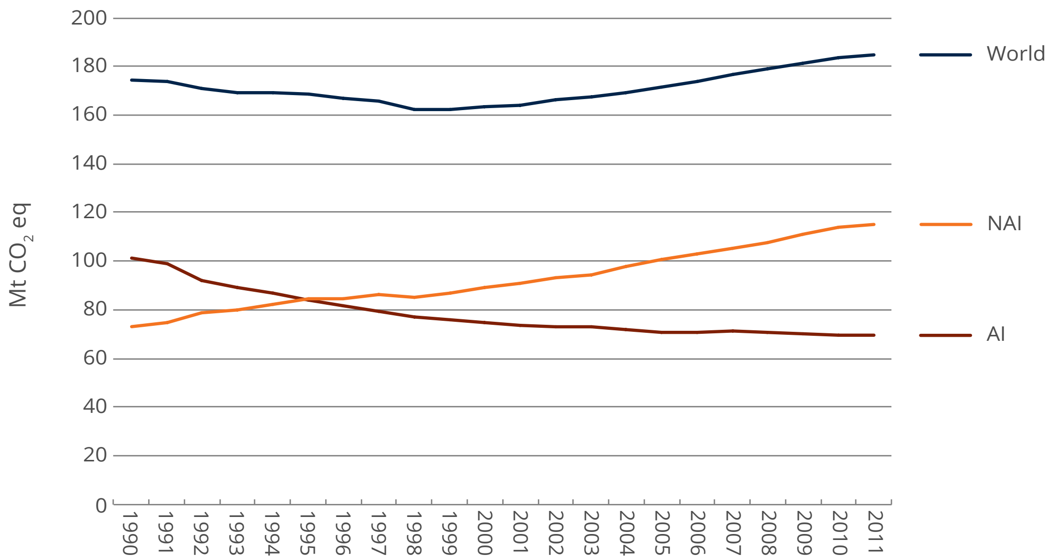


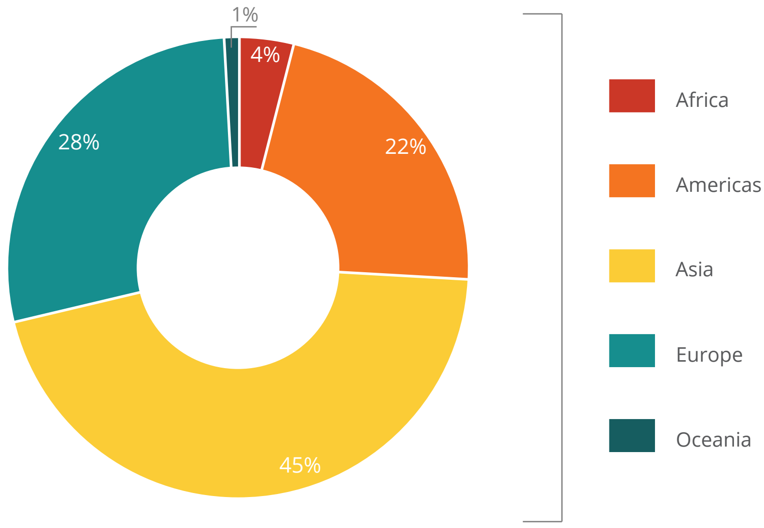
FIGURE 4-11 Historical trends in emissions from manure applied to soils, 1990-2011.

TABLE 4-5 Manure applied to soils emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	87	72	69
NAI	82	99	115
World	168	171	185

2001-2011 Trends: by Continent

Asia was the largest contributor (45%), followed by Europe (28%) and the Americas (22%), while Africa had a small share of total emissions (4%). (Fig. 4-12.a). Average annual emissions growth rates over the same period were largest in Africa (3.7% yr^{-1}) and Asia (2.5% yr^{-1}), while they were negative in Europe (-0.9% yr^{-1}) (Fig. 4-12.b).



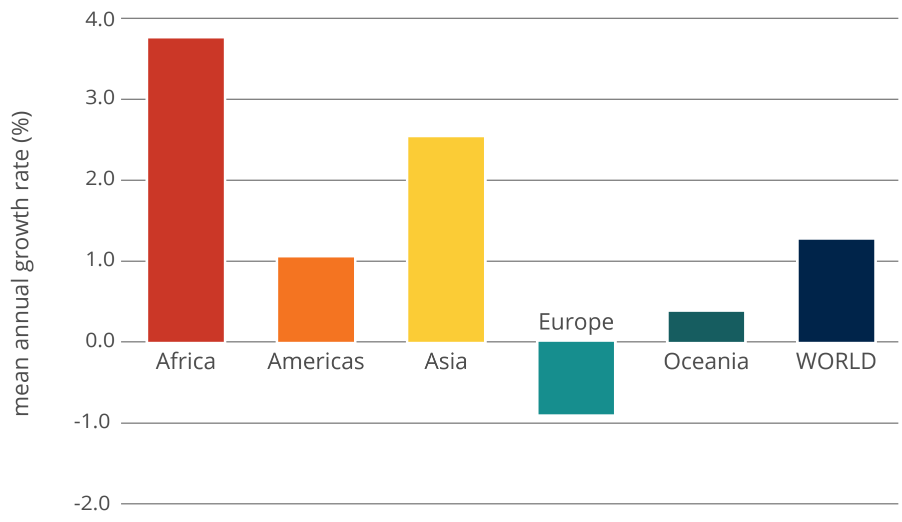


FIGURE 4-12 Manure applied to soils, 2001-2011: (a) emissions and (b) annual growth rates, by continent.

2001-2011 Trends: Sub-sectors

Emissions from manure applied to soil were dominated by cattle, contributing 45% of all emissions (23% non-dairy cattle; 22% dairy cattle), followed by swine (18%), buffaloes (7%) and sheep (5%) (Fig. 4-13).

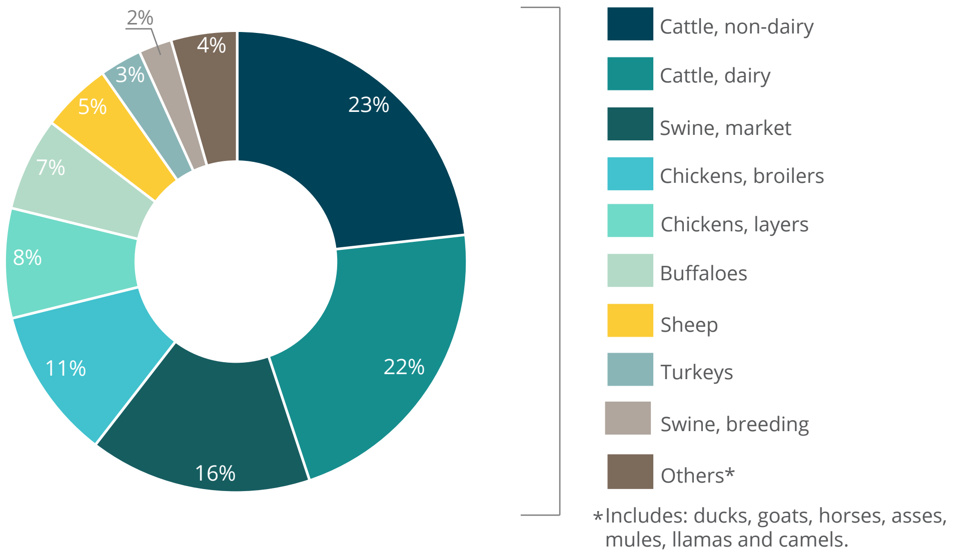


FIGURE 4-13 Manure applied to soils by sub-sector, 2001-2011.

Projections: 2030 and 2050

With respect to average 2000's levels, global emissions from manure applied to soils are projected to increase by 26% and 42% in 2030 and 2050, respectively, reaching more than 240 Mt CO_2 eq in 2050.

4.4.3 Manure left on pasture

Greenhouse gas emissions from manure left on pasture consist of nitrous oxide, N_2O, produced from nitrogen additions to managed soils from grazing livestock. Estimates include emissions by cattle, buffaloes, sheep, goats, camels, llamas, horses, mules, asses, ducks, turkeys, chickens and swine.

2011

In 2011, world total annual GHG emissions from manure left on pasture were 824 Mt CO_2 eq, more than 15% of total emissions from agriculture in the same year. Emissions in non-Annex I countries represented more than 80% of the total.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased 16%, from 712 to 824 Mt CO_2 eq. Emissions growth took place almost entirely in non-Annex I countries (i.e., +22%, from 568 to 692 Mt CO_2 eq), while it decreased by -8% in Annex I countries. From 1990 to 2011, emissions decreased in Annex I countries by -23%, but increased by 43% in non-Annex I countries (Fig. 4-14).

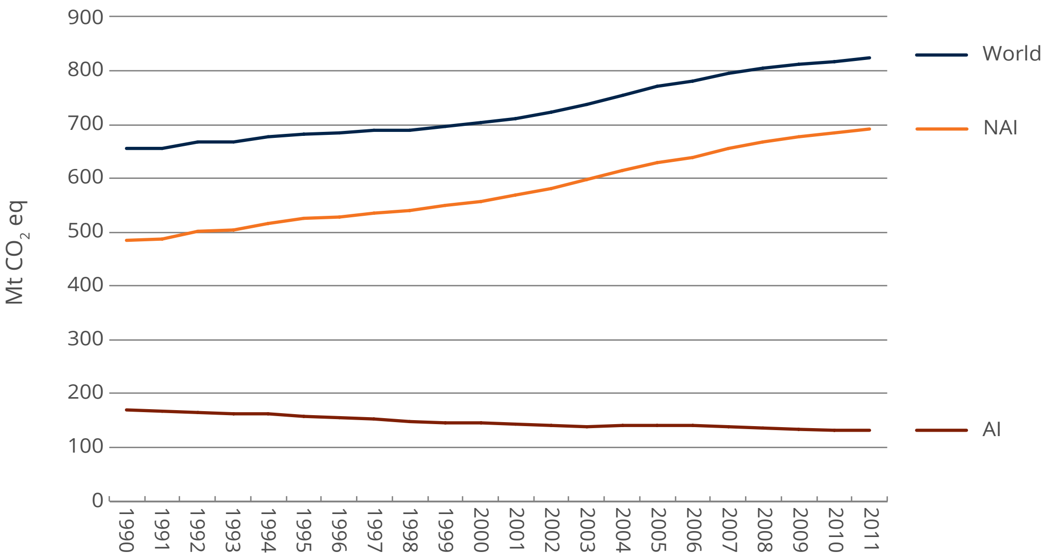


FIGURE 4-14 Historical trends in emissions from manure left on pasture, 1990-2011.

2001-2011 Trends: by Continent

The Americas (33%) and Asia (31%) were the largest contributors, followed by Africa (25%), Oceania (6%) and Europe (5%) (Fig. 4-15.a). Average annual emissions growth rates over the same period were largest in Africa (2.8% yr^{-1}) and Asia (2.2% yr^{-1}). They were negative in Oceania (-1.5% yr^{-1}) and Europe (-1.1% yr^{-1}) (Fig. 4-15.b).

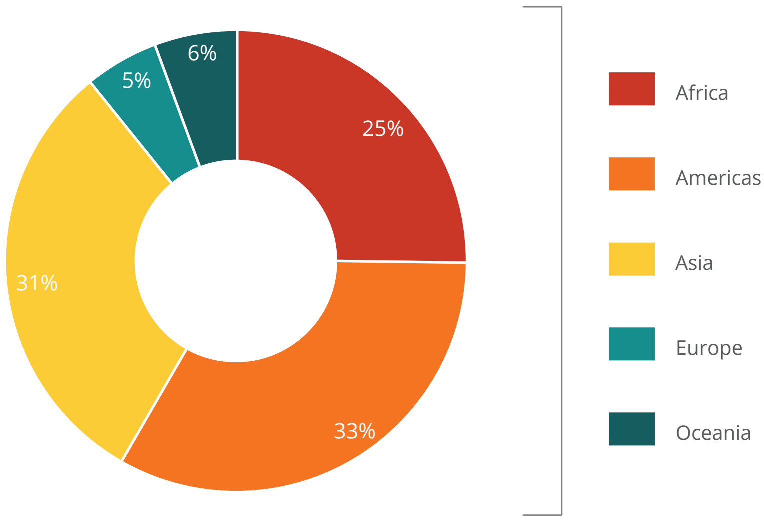


FIGURE 4-15a Manure left on pasture, 2001-2011: emissions by continent.

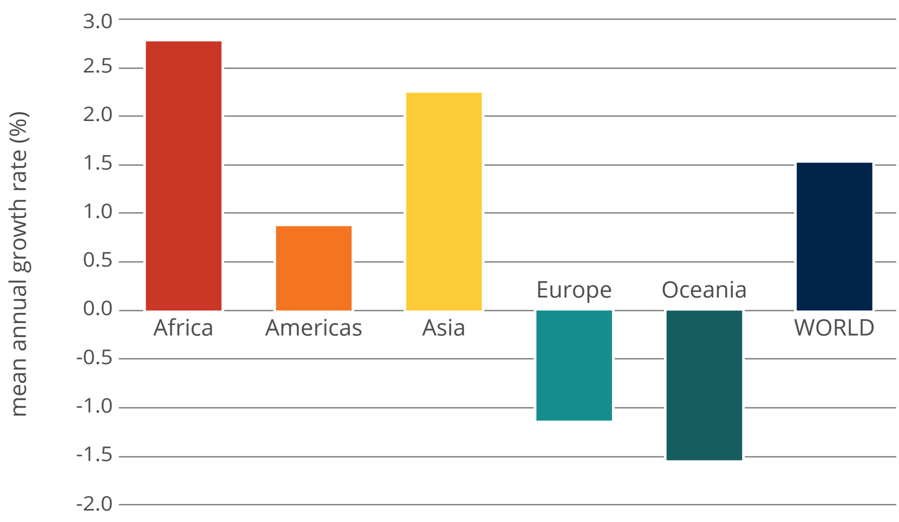


FIGURE 4-15b Manure left on pasture, 2001-2011: annual growth rates by continent.

2001-2011 Trends: Sub-sectors

Emissions of manure left on pasture were dominated by cattle, contributing 62% of the total (51% non-dairy cattle; 11% dairy cattle), followed by sheep (12%), goats (12%) and buffaloes (5%) (Fig. 4-16).

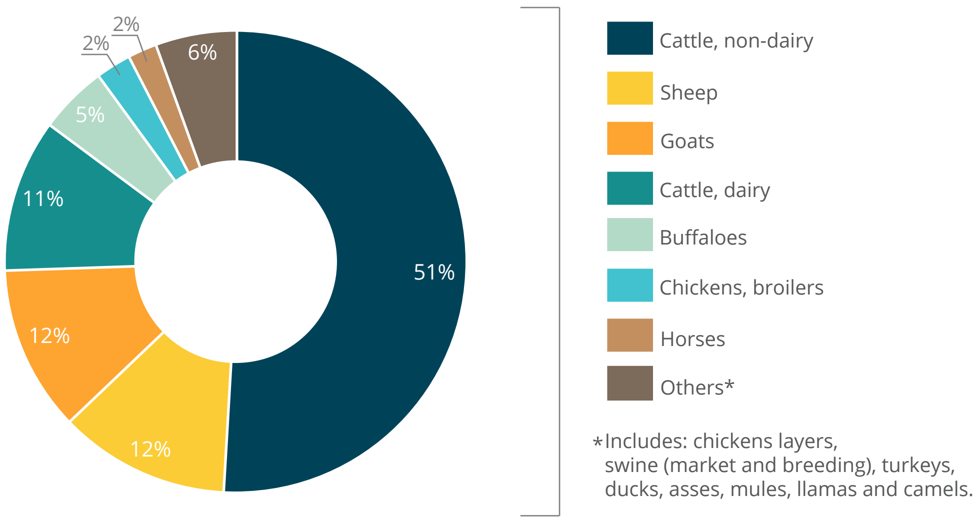


FIGURE 4-16 Manure left on pasture by sub-sector, 2001-2011

TABLE 4-6 Manure left on pasture emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	159	140	132
NAI	518	619	692
World	677	759	824

Projections: 2030 and 2050

With respect to average 2000's levels, global emissions from manure left on pasture are projected to increase in 2030 and 2050 by 23% and 40%, respectively, reaching more than 1,000 Mt CO_2 eq in 2050.

4.4.4 Crop Residues

Greenhouse gas emissions from crop residues consist of direct and indirect nitrous oxide (N_2O) emissions from nitrogen in crop residues and forage/pasture renewal left on agricultural fields by farmers. Specifically, N_2O is produced by microbial processes of nitrification and de-nitrification taking place on the deposition site (direct emissions), and after volatilization/re-deposition and leaching processes (indirect emissions).

2011

In 2011, world total annual emissions from crop residues were 197 Mt CO_2 eq, nearly 4% of total emissions from agriculture. Emissions in non-Annex I countries were nearly two-thirds of the total.

TABLE 4-7 Crop residues emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	64	67	71
NAI	92	1067	126
World	156	174	197

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased by 20%, from 164 to 197 Mt CO_2 eq. Emissions growth was stronger in non-Annex I countries (i.e., 27% from 99 to 126 Mt CO_2 eq). Since 1990, emissions increased in non-Annex I countries by 48% but only by 4% in Annex I countries (Fig. 4-17).

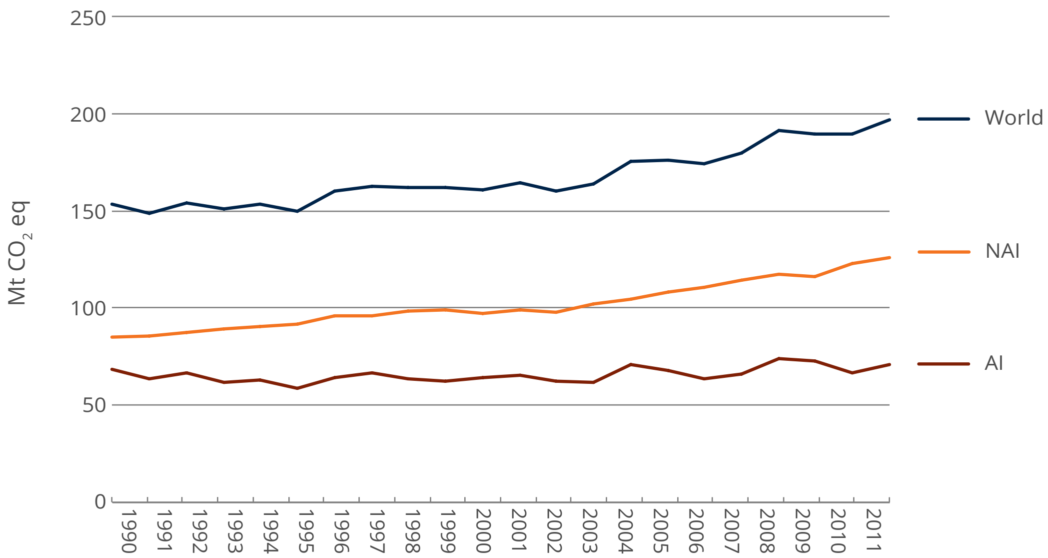


FIGURE 4-17 Historical trends in emissions from crop residues, 1990-2011.

2001-2011 Trends: by Continent

Asia was the largest emitter (47%), followed by the Americas (27%), Europe (17%), and Africa (7%) (Fig. 4-18.a). Annual average emissions growth rates over the same period were largest in Africa (3.0% yr^{-1}) and the Americas (2.5% yr^{-1}), followed by Asia (2.2% yr^{-1}), while they were the lowest in Europe 0.5% yr^{-1} (Fig. 4-18.b).

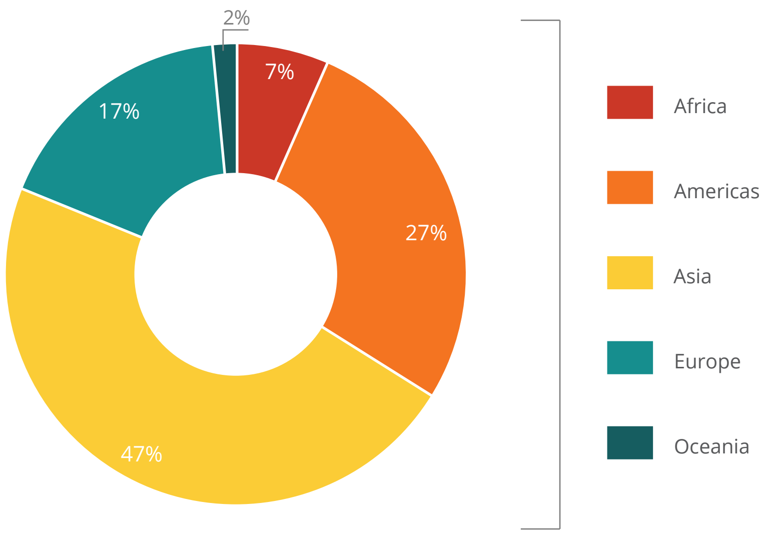


FIGURE 4-18a Crop residues, 2001-2011: emissions by continent.

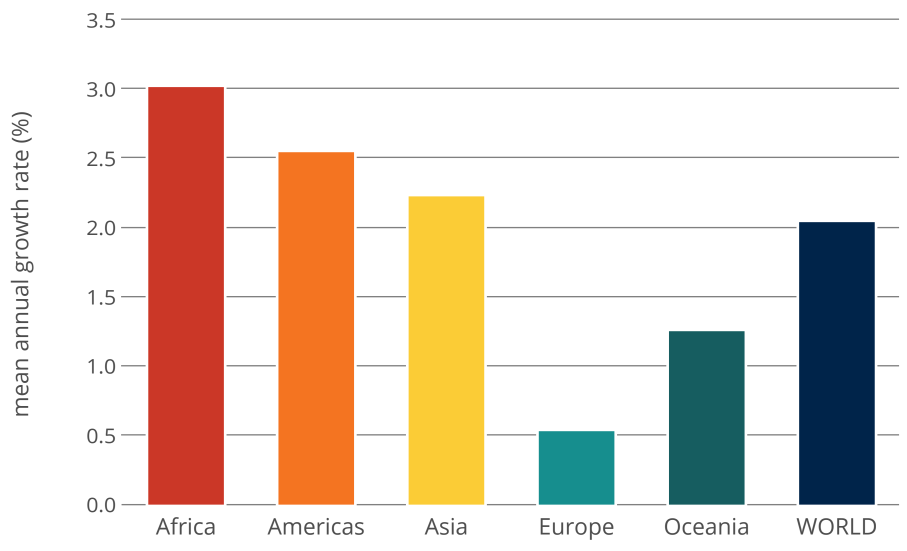


FIGURE 4-18b Crop residues, 2001-2011: annual growth rates by continent.

2001-2011 Trends: Sub-sectors

Emissions of crop residues were dominated by rice and wheat, both contributing 27%, followed by maize (21%) and soybeans (10%) (Fig. 4-19).

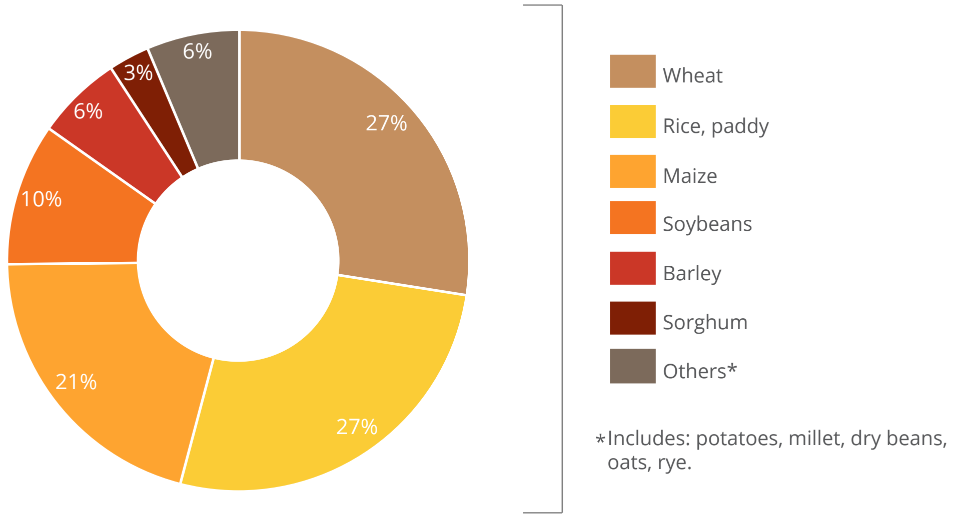


FIGURE 4-19 Crop residues by sub-sector, 2001-2011

Projections: 2030 and 2050

With respect to average 2000's levels, global emissions from crop residues are projected to increase in 2030 and 2050 by 25% and 35%, respectively, reaching 235 Mt CO_2 eq in 2050.

4.4.5 Cultivation of organic soils

Greenhouse gas emissions from cultivation of organic soils are those associated with nitrous oxide (N_2O) emissions from the drainage of cropland and grassland histosols (peatlands). Emissions of CO_2, which are more significant, are reported under FOLU. Organic soils amount to about 328 M ha worldwide, of which 26 M ha (7.8%) are estimated as being cultivated. Estimates of N_2O emissions from cultivation of organic soils in the FAOSTAT Emissions database are a constant over the entire period 1990-2011.

2001-2011 Trends: by Continent

Asia (39%) and Europe (35%) were the largest contributors, followed by the Americas (16%) (Fig. 4-20)

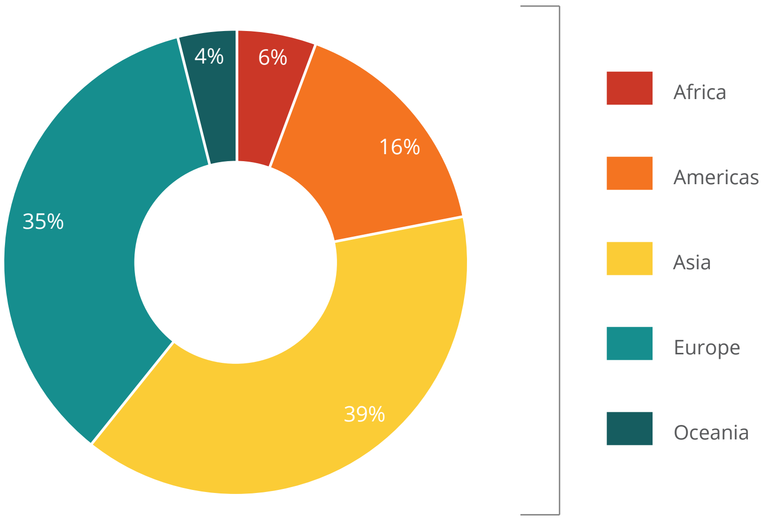


FIGURE 4-20 Cultivation of organic soils: emissions by continent.

2001-2011 Trends: Sub-sectors

Emissions from cultivation of organic soils in agriculture originate for three-fourths in cropland areas (Fig. 4-21). World total annual emissions from cropland organic soils were 99 Mt CO_2 eq and 34 Mt CO_2 eq from grassland organic soils.

TABLE 4-8 Cultivation of organic soils emissions by sub-sector, average 1990-2011 (Mt CO_2 eq)

Countries	Cropland	Grassland	Total
AI	43	24	67
NAI	56	10	66
World	99	34	133

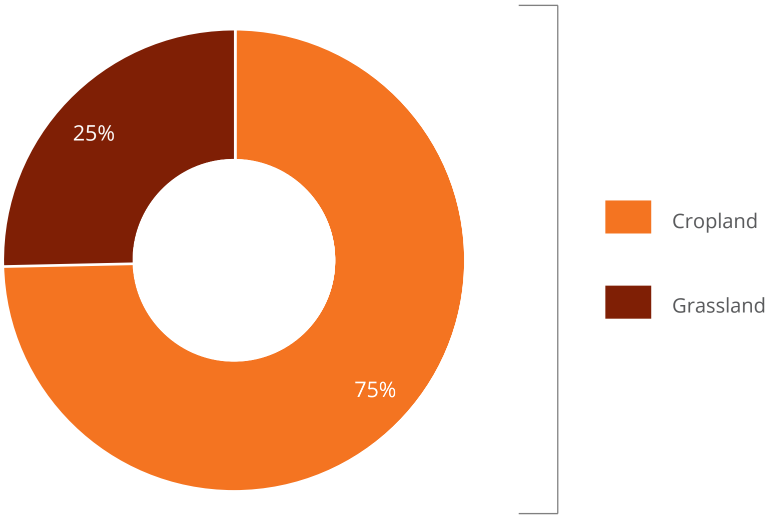


FIGURE 4-21 Cultivation of organic soils by sub-sector, 2001-2011

In summary, N_2O emissions from cultivation of organic soils, comprised of emissions from cropland and grassland organic soils, totalled 133 Mt CO_2 eq, roughly equally split between Annex I and non-Annex I countries.

4.5 Burning of savanna

Greenhouse gas emissions from burning of savanna consist of methane (CH_4) and nitrous oxide (N_2O) produced from the burning of vegetation biomass in the following five land cover types: *savanna, woody savanna, open shrubland, closed shrubland* and *grassland*.

2011

In 2011, world total annual emissions from burning of savanna were 287 Mt CO_2 eq, nearly 5% of total emissions from agriculture. Emissions in non-Annex I countries were nearly two-thirds of the total.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions remained fairly stable, i.e., from 285 Mt CO_2 eq to 287 Mt CO_2 eq. Emissions grew by 5% in Annex I countries while they decreased in non-Annex I countries (-1%) (Fig. 4-22).

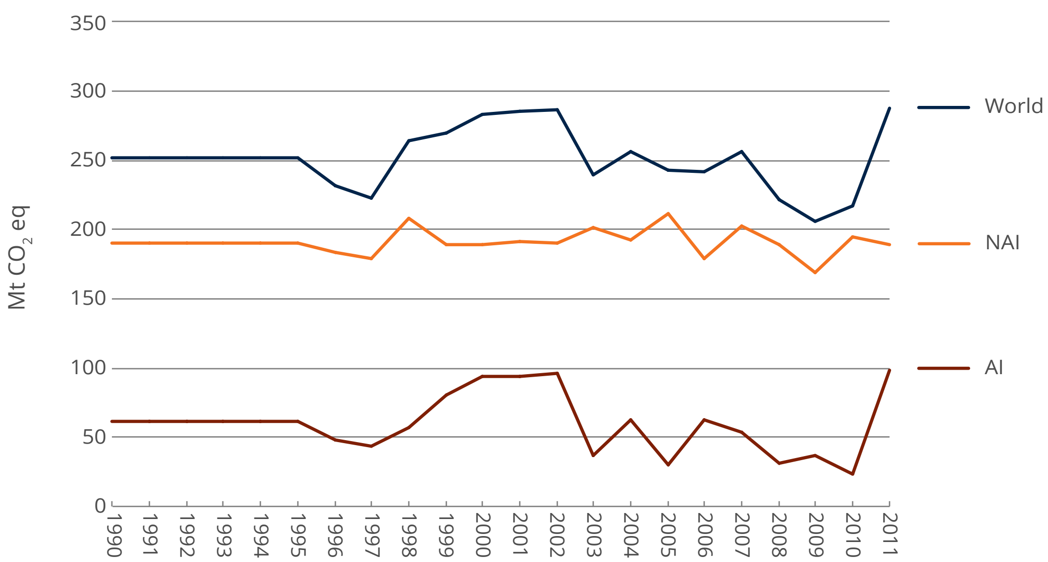


FIGURE 4-22 Historical trends in emissions from burning of savanna, 1990-2011.

2001-2011 Trends: by Continent

Africa was by far the largest emitter (70%), followed by Oceania (19%) and the Americas (7%) (Fig. 4-23.a). Annual average emissions growth rates were negative in all regions over this period, with the largest decrease in Oceania (-6.1% yr^{-1}), followed by the Americas (-4.4% yr^{-1}) and Europe (-3.5%). (Fig. 4-23.b).

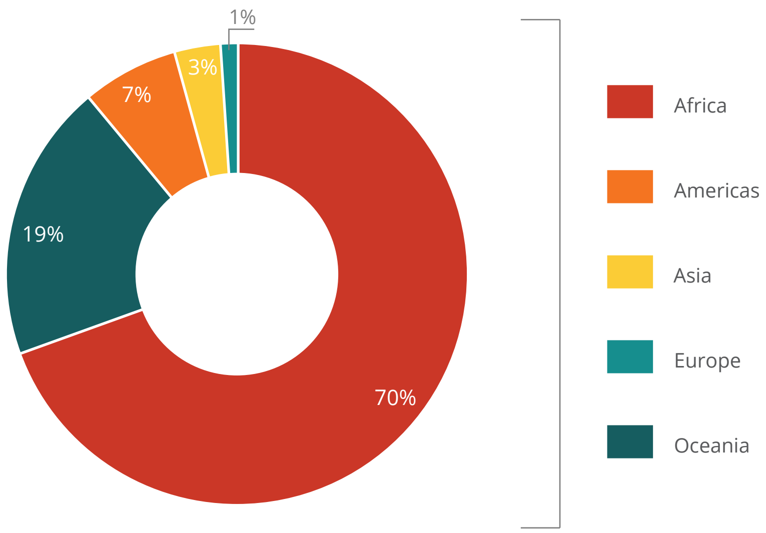


FIGURE 4-23a Burning of savanna, 2001-2011: emissions by continent.

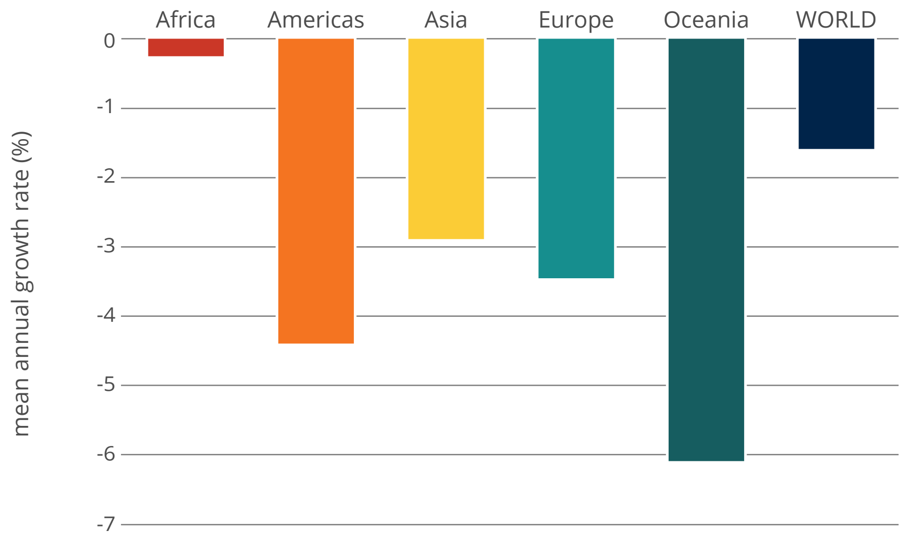


FIGURE 4-23b Burning of savanna, 2001-2011: annual growth rates by continent.

2001-2011 Trends: Sub-sectors

Emissions from burning of savanna were dominated by savanna (39%) and woody savanna (35%), followed by open shrubland and grassland (14% and 9%, respectively) (Fig. 4-24).

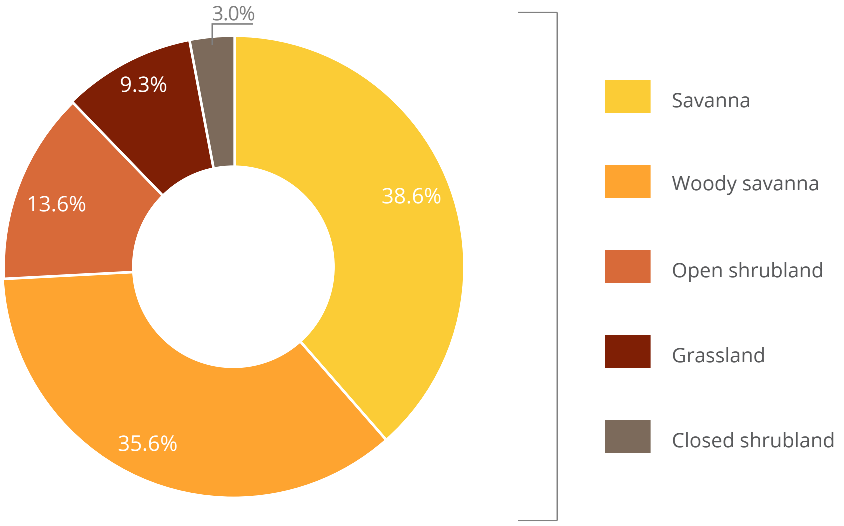


FIGURE 4-24 Burning of savanna by sub-sector, 2001-2011

TABLE 4-9 Burning of savanna emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	60	60	99
NAI	190	192	189
World	250	252	288

Projections: 2030 and 2050

With respect to the 2000s, global emissions from burning of savanna are projected to decrease by -7% in 2030 and 2050, respectively, to 252 Mt CO_2 eq.

4.6 Burning of crop residues

Greenhouse gas emissions from burning crop residues consist of methane (CH_4) and nitrous oxide (N_2O) produced by the combustion of crop residues burnt in agricultural fields.

2011

In 2011, world total annual emissions from burning of crop residues were 29 Mt CO_2 eq, or only 0.5% of total emissions from agriculture. Emissions in non-Annex I countries were more than two-thirds of the total.

2001-2011 Trends: Global

Over the period 2001-2011, total annual emissions increased 15%, from 25 to 29 Mt CO_2 eq. Emissions in non-Annex I countries represented two-thirds of the total (Fig. 4-25).

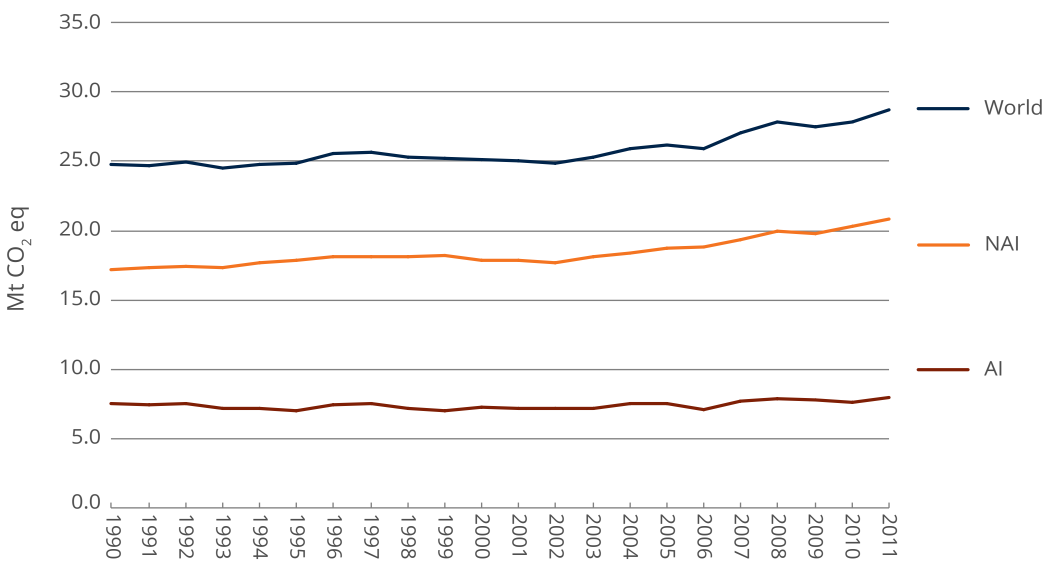
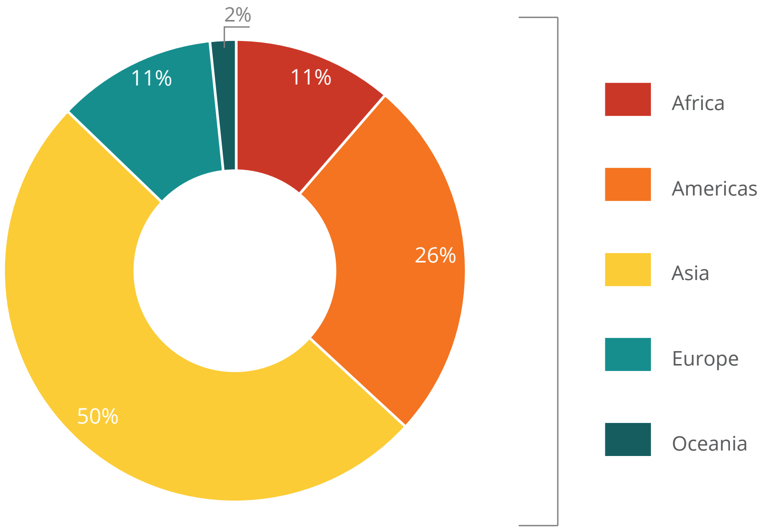


FIGURE 4-25 Historical trends in emissions from burning of crop residues, 1990-2011.

2001-2011 Trends: by Continent

Asia was the largest emitter (50%), followed by the Americas (26%), Africa and Europe (both with a 11% share) (Fig. 4-26.a). Annual average emissions growth rates over the same period were largest in Africa (2.7% yr^{-1}) and Asia (1.5% yr^{-1}), while the Americas and Oceania were both 1.2%yr^{-1}), and Europe 0.7% yr^{-1} (Fig. 4-26.b).



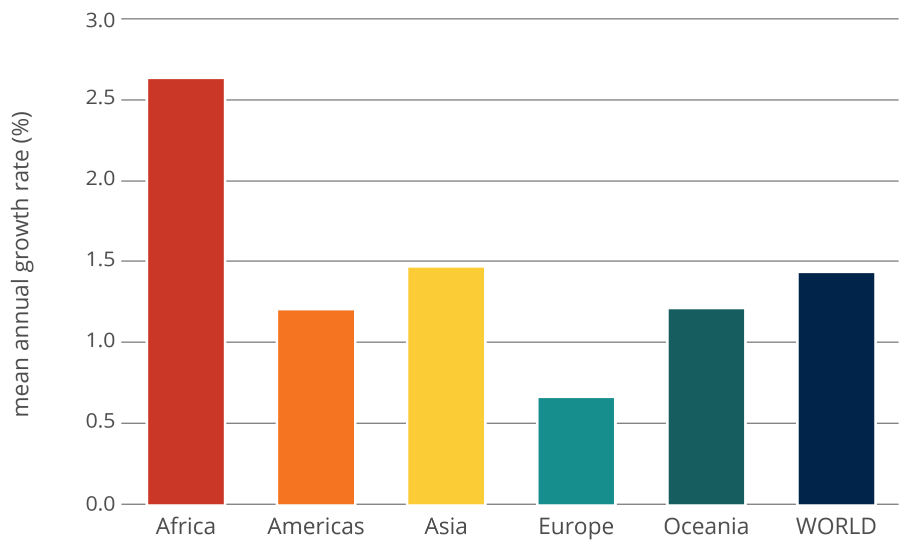


FIGURE 4-26 Burning of crop residues, 2001-2011: (a) emissions and (b) annual growth rates, by continent.

2001-2011 Trends: Sub-sectors

Emissions from burning of crop residues were dominated by maize, contributing 45%, followed by wheat and rice (26% and 25%, respectively) (Fig. 4-27).

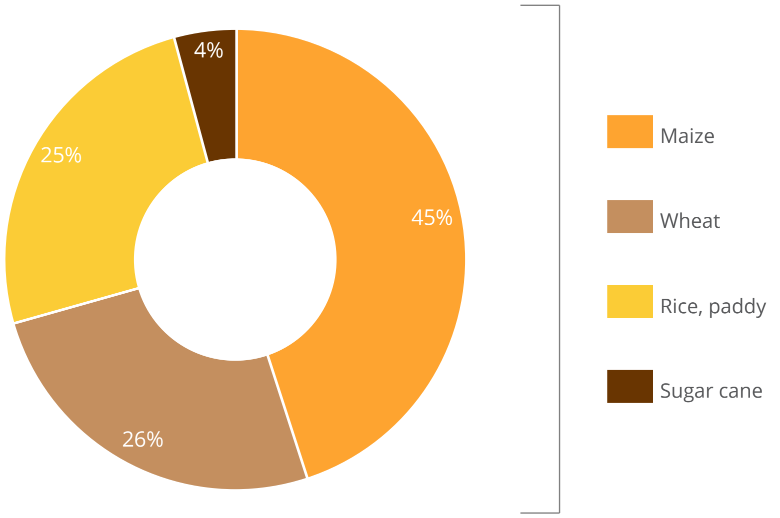


FIGURE 4-27 Burning of crop residues by sub-sector, 2001-2011

TABLE 4-10 Burning of crop residues emissions by decade and in 2011 (Mt CO_2 eq)

Countries	1990s	2000s	2011
AI	7	7	8
NAI	18	19	21
World	25	26	29

Projections: 2030 and 2050

With respect to the levels of the decade 2000s, global emissions from burning of crop residues are projected to increase by 8% and 11% in 2030 and 2050, respectively, reaching 29 Mt CO_2 eq in 2050.

5. FORESTRY AND OTHER LAND USE

5.1 Forest Land

5.1.1 Net Forest Conversion

Greenhouse gas emissions from net forest conversion consist of carbon dioxide, CO_2, produced by the oxidation of carbon in biomass stock lost due to conversion of forest land to other land uses, mainly to agriculture as either cropland or grazing land. The term ***net*** refers to the annual difference between forest land area gains and losses. The latter cannot be separated from the national forest statistics available in FAOSTAT.

2010

In 2010, world total annual GHG emissions from net forest conversion were 3,738 Mt CO_2 eq. This amount represents about 70% of total emissions from the agriculture sector in the same year, and less than half of total emissions from AFOLU. Emissions in non-Annex I countries represented more than 90% of the total.

2001-2010 Trends: Global

Over the period 2001-2010, global emissions decreased by 3%, from 3,837 to 3,738 Mt CO_2 eq. The decrease took place in both non-Annex I countries (i.e., -2%, from 3,610 to 3,521 Mt CO_2 eq), and Annex I countries (i.e., -4%, from 227 to 217 Mt CO_2 eq). From 1990 to 2010, emissions decreased in non-Annex I countries by -19%, while they increased by 44% in Annex I countries (Fig. 5-1).

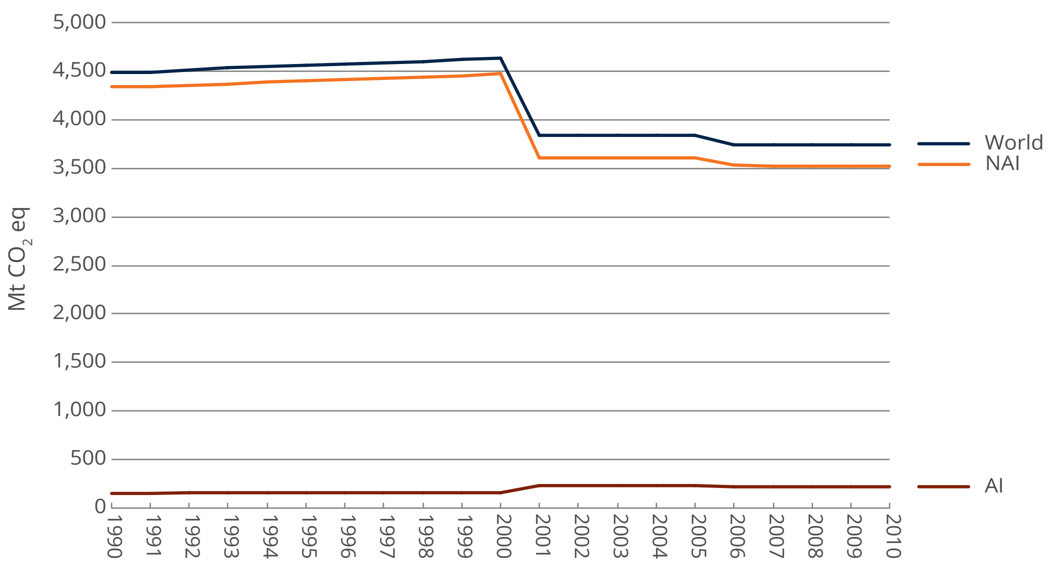


FIGURE 5-1 Historical trends in emissions/removals from net forest conversion, 1990-2010.

2001-2010 Trends: by Continent

The Americas were the largest contributor (54%), followed by Africa (26%) and Asia (15%) (Fig. 5-2.a). Annual average emissions growth rates over the same period were positive in Oceania (+13.4% yr^{-1}), Asia (+4.1% yr^{-1}) and Africa (+0.2% yr^{-1}), while they were negative in Europe (-29.2% yr-1) and the Americas (-2.1% yr^{-1}) (Fig. 5-2.b).

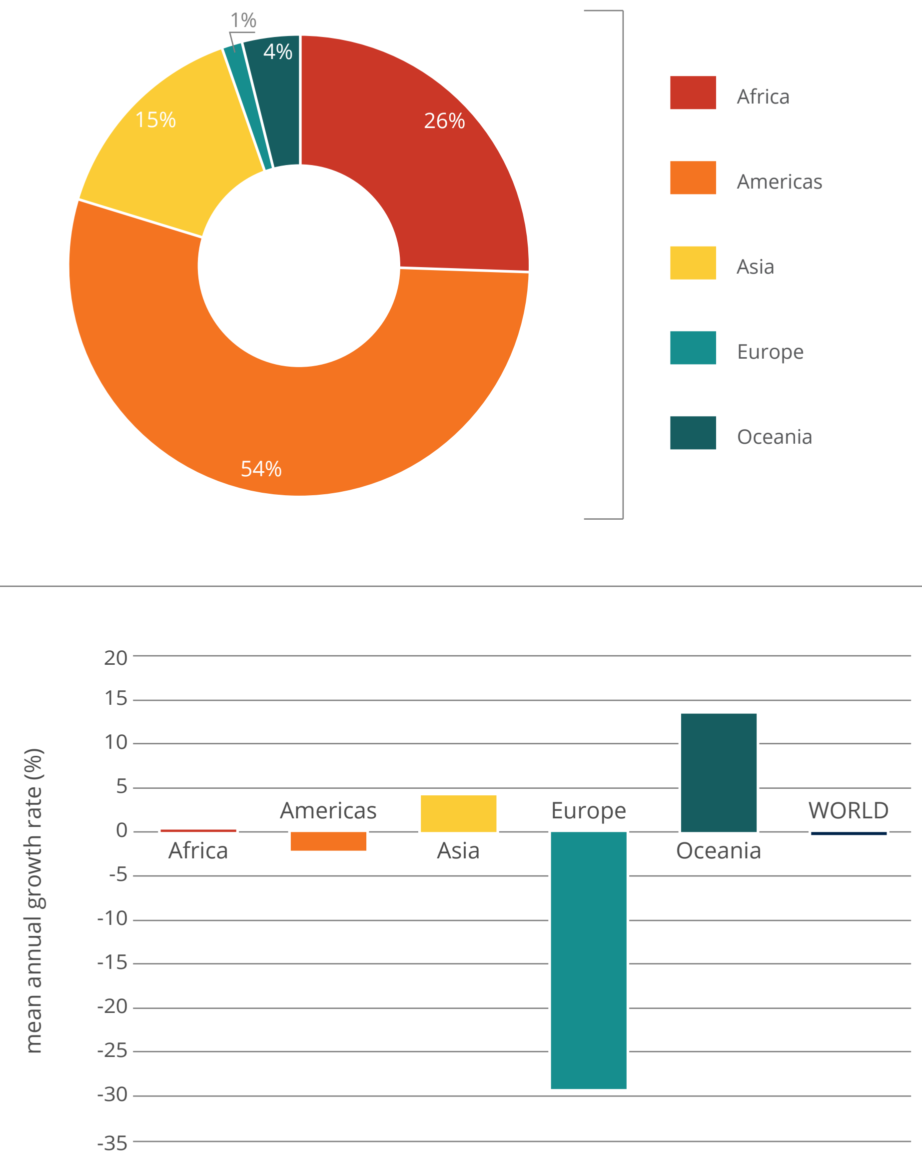


FIGURE 5-2 Net forest conversion, 2001-2010: (a) emissions/removals and (b) annual growth rates, by continent.

TABLE 5-1 Net forest conversion net emissions/removals by decade and in 2010 (Mt CO_2 eq)

Countries	1990s	2000s	2010
AI	159	216	217
NAI	4,395	3,663	3,521
World	4,554	3,879	3,738

5.1.2 Forest

Greenhouse gas emissions by sources and/or removals by sinks from forest consist of carbon dioxide, CO_2, generated by the oxidation and fixation of carbon in biomass stocks associated with forest land use, including net forest expansion and forest degradation.

2010

In 2010, world total annual CO_2 emissions minus removals from forest resulted in a net sink, i.e., net removals of -2,050 Mt CO_2 eq, a value almost 10% higher than the 2001-2010 average. Since the year 2001, Annex I countries have contributed about two-thirds of the total sink. By contrast, non-Annex I countries had a stronger net sink during the period 1990-1999.

2001-2010 Trends: Global

Over the period 2001-2010, the strength of the global forest sink increased by 21%, from -1,692 to -2,050 Mt CO_2 eq, taking place almost entirely in Annex I countries (i.e., 31%, from -1,106 to -1,452 Mt CO_2 eq), while it remained rather stable in non-Annex I countries, growing only by 2%. Such trend is reversed over the longer period 1990-2010, when the global sink decreased overall by -28%, a result of a 68% increase in Annex I countries and a -70% decrease in non-Annex I countries (Fig. 5-3).

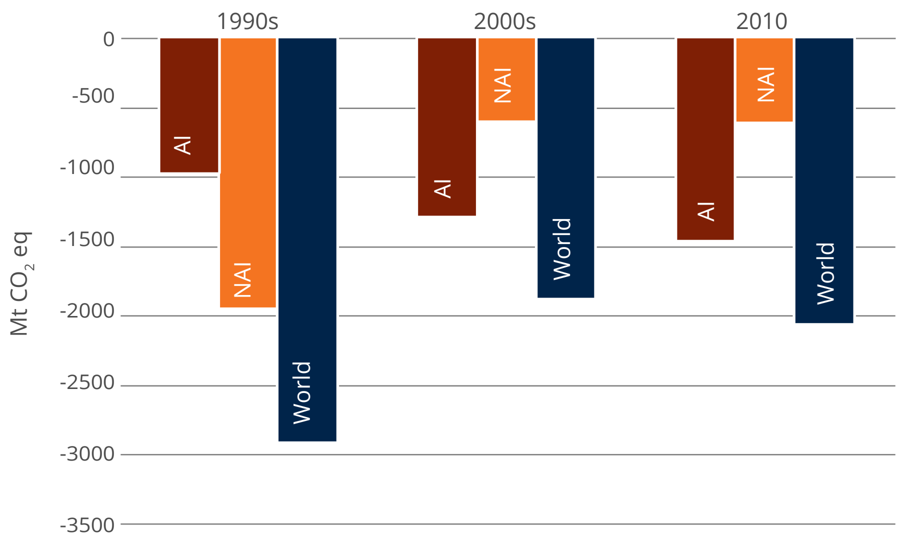


FIGURE 5-3 Historical trends in emissions/removals from forest, 1990-2010.

2001-2010 Trends: by Continent

During this period all continents had net removals, i.e., they were net FOLU sinks. The Americas were the largest contributor to the global forest sink (44%), followed by Europe (36%) and Asia (10%) (Fig. 5-4.a). Annual average sink increases are estimated over the same period in Oceania (+20.7% yr-1), followed by the Americas (+3.2% yr-1), and Europe (+1.7% yr-1), while forest sink strength decreased in Asia (-6.3% yr-1) and Africa (-2.0% yr-1) (Fig. 5-4.b).

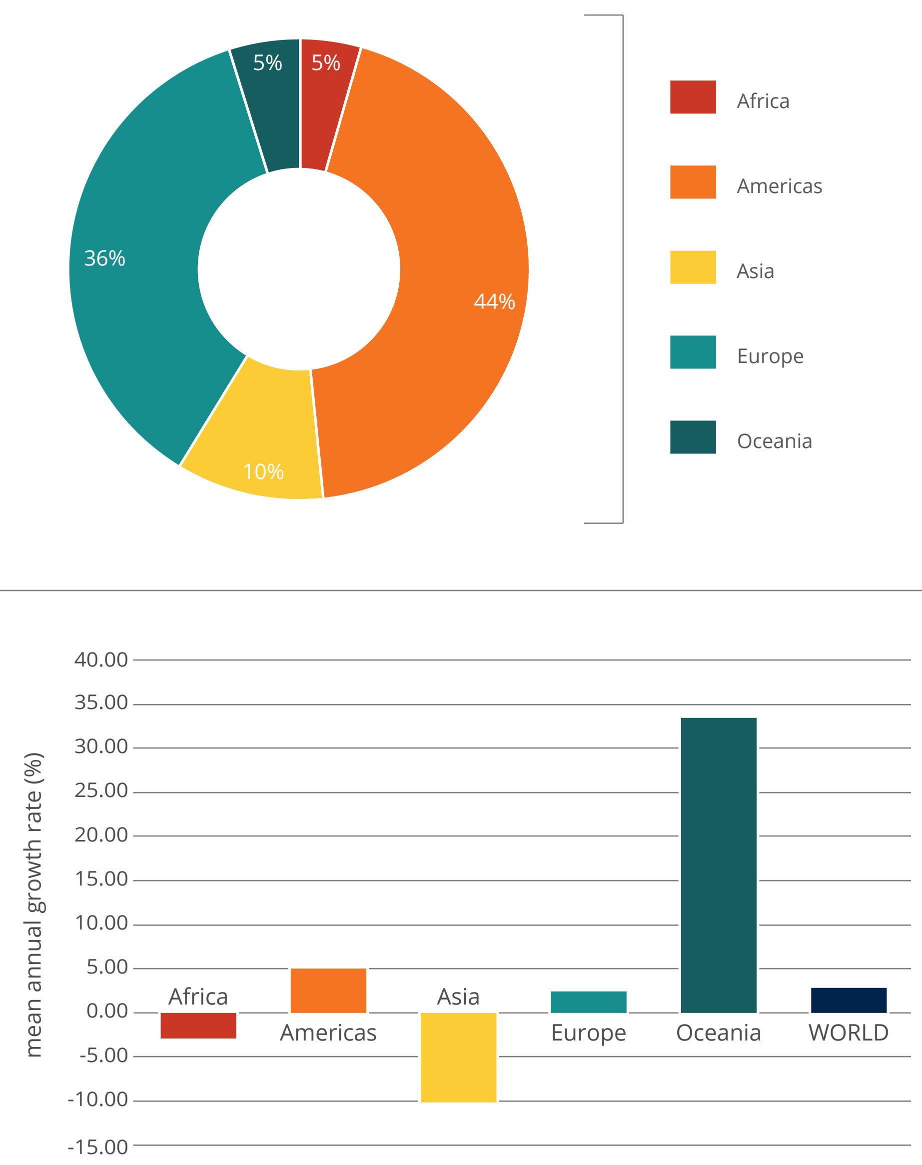


FIGURE 5-4 Forest, 2001-2010: (a) Net removals and (b) annual growth rates, by continent.

TABLE 5-2 Forest net removals by decade and in 2010 (Mt CO_2 eq)

Countries	1990s	2000s	2010
AI	-964	-1,235	-1,452
NAI	-1,941	-722	-598
World	-2,905	-1,868	-2,050

5.2 Cropland

Greenhouse gases emissions in cropland are those associated with CO_2 emissions from the drainage of organic soils (i.e. histosols, peatlands) for crop production. As discussed in the section 4.4.4, these estimates of CO_2 emissions from cultivation of organic soils are represented by a constant yearly value, representing an average for the entire period 1990-2011.

Total annual emissions from cropland organic soils are estimated at 756 Mt CO_2 eq, or 25% of total emissions by sources from FOLU. Emissions in non-Annex I countries were two-thirds of the total (Table 5-3).

2001-2010 Trends: by Continent

These trends are of the same as those reported for N_2O emissions in agriculture. Asia (55%) and Europe (20%) were the largest contributors, followed by the Americas (13%) (Fig. 5-5).

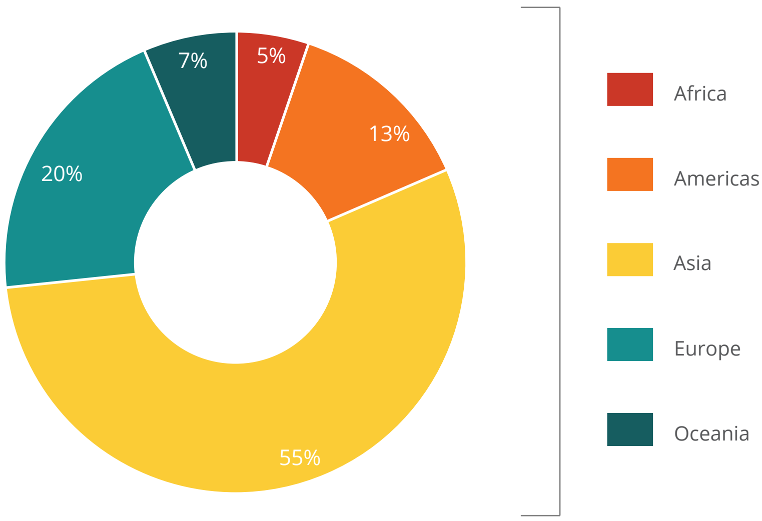


FIGURE 5-5 Cropland: emissions by continent.

TABLE 5-3 Cropland emissions, 1990-2011 mean value (Mt CO_2 eq).

Countries	1990s	2000s	2011
AI	252	252	252
NAI	505	505	505
World	756	756	756

5.3 Grassland

Greenhouse gases emissions in grassland are those associated with CO_2 emissions from the drainage of organic soils (histosols, peatlands) for livestock production. As discussed in the section 4.4.4, these estimates of CO_2 emissions from cultivation of organic soils are represented by a constant yearly value over the entire period 1990-2011.

Total annual emissions from grassland organic soils were 25 Mt CO_2 eq. Emissions in non-Annex I countries were more than two-thirds of the total.

2001-2010 Trends: by Continent

Asia was the largest contributor (42%), followed by the Americas (20%) and Africa (21%) (Fig. 5-6).

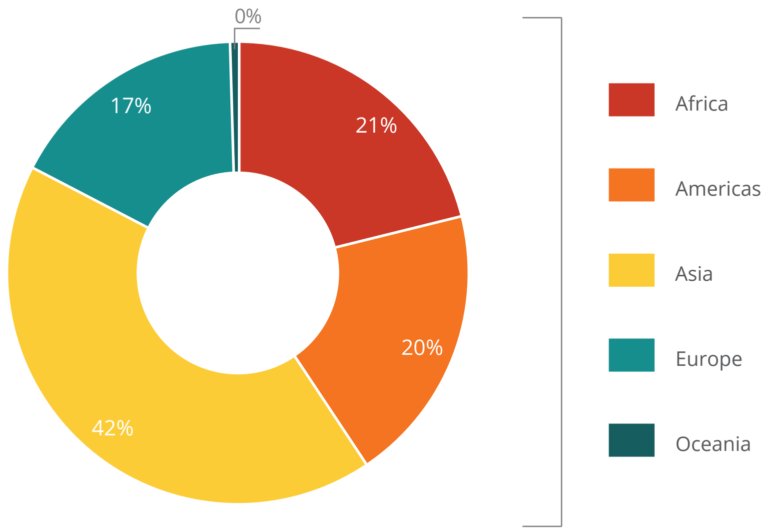


FIGURE 5-6 Grassland: emissions by continent.

TABLE 5-4 Grassland emissions, 1990-2011 mean value (Mt CO_2 eq).

Countries	1990s	2000s	2011
AI	8	8	8
NAI	18	18	18
World	26	26	26

5.4 Burning biomass

Emissions from burning of biomass consist of methane (CH_4) and nitrous oxide (N_2O) from the combustion of biomass in forest areas (land cover classes 'Humid and Tropical Forest' and 'Other Forests'), and of methane, nitrous oxide, and carbon dioxide gas from the combustion of organic soils.

2011

In 2011, world total annual emissions from burning biomass were 290 Mt CO_2 eq, nearly 10% of total emissions from FOLU. Emissions in non-Annex I countries were nearly two-thirds of the total.

2001-2011 Trends: Global

Over the period 2001-2011, annual emissions increased by more than 40%, i.e., from 206 to 290 Mt CO_2 eq. Emissions grew by 63% in Annex I countries and by 32% in non-Annex I countries. The period 1997-1998 was characterized by higher than average emissions, reaching above 500 Mt CO_2 eq in 1998 (Fig. 5-7).

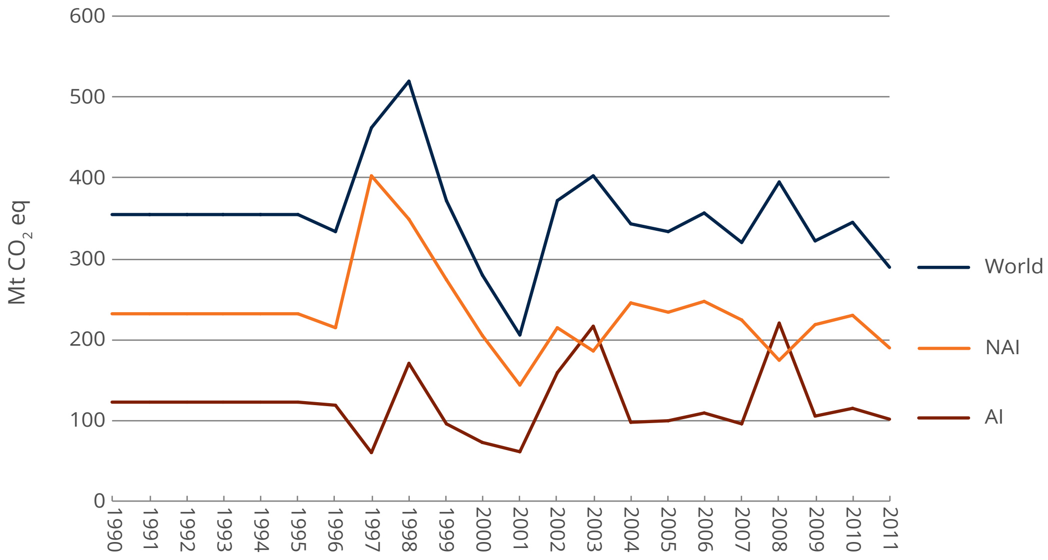
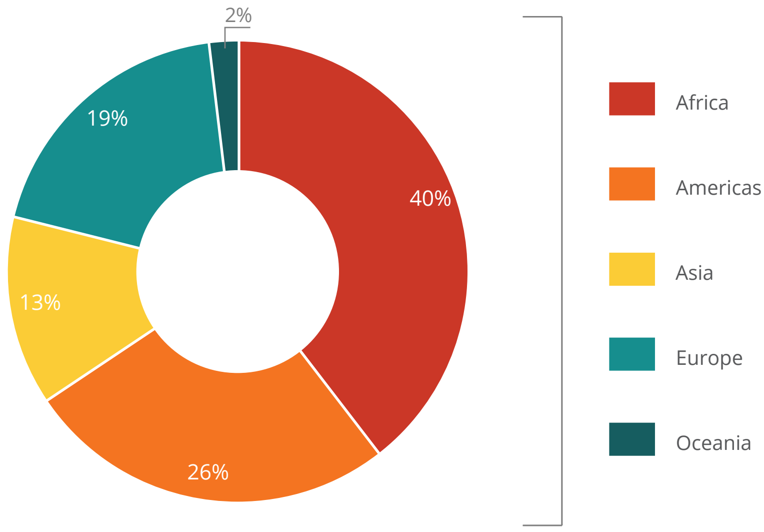


FIGURE 5-7 Historical trends in emissions from burning biomass, 1990-2011.

2001-2011 Trends: by Continent

Africa was the largest contributor (40%), followed by the Americas (26%), Europe (19%) and Asia (13%) (Fig. 5-8.a). Annual average emissions growth was negative in Oceania (-9.2% yr^{-1}). By contrast, positive growth in emissions took place in the Americas (+3.9% yr^{-1}) and Asia (1.6% yr-1) (Fig. 5-8.b).



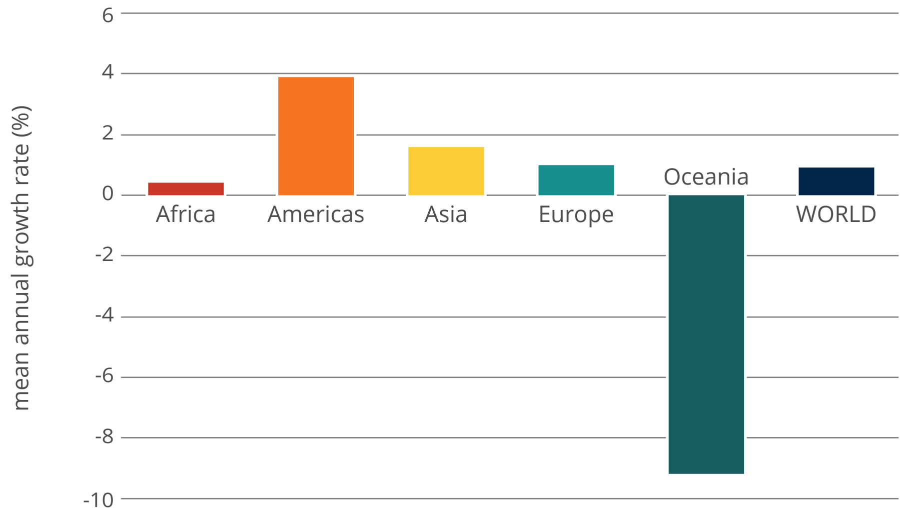


FIGURE 5-8 Burning biomass, 2001-2011: (a) emissions and (b) annual growth rates, by continent.

2001-2011 Trends: Sub-sectors

Emissions from burning biomass were dominated by burning of organic soils (59%), followed by fires in humid tropical forest (27%)—largely related to deforestation activities—and fires in temperate and boreal forest (14%) (Fig. 5-9).

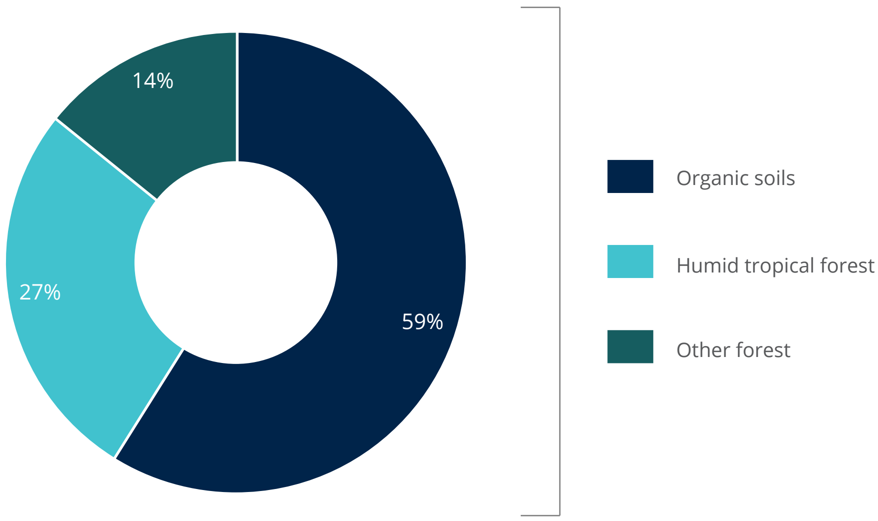


FIGURE 5-9 Burning biomass by sub-sector, 2001-2011.

TABLE 5-5 Biomass burning emissions by decade and in 2011 (Mt CO_2 eq).

Countries	1990s	2000s	2011
AI	118	124	101
NAI	264	210	189
World	382	333	290

6. ENERGY USE IN AGRICULTURE

Emissions from energy use in agriculture consist mainly of CO_2 and minor emission of methane, CH_4, and nitrous oxide, N_2O, produced by fossil fuel burning for machinery, power irrigation, and fishing vessels. Estimates include emissions by main energy carriers: gas-diesel oils, gasoline, natural gas (including liquified natural gas), liquified petroleum gas, residual fuel oil, hard coal and electricity.

2010

In 2010, world total annual GHG emissions from energy use were 785 Mt CO_2 eq, adding about 15% to total non-energy emissions from agriculture in the same year. Emissions in non-Annex I countries represented about 70% of the total.

2000-2010 Trends: Global

Over the period 2000-2010, emissions increased 20%, from 651 to 785 Mt CO_2 eq. Emissions growth took place largely in non-Annex I countries (i.e., 40% increase, from 392 to 553 Mt CO_2 eq), while it decreased in Annex I countries by -10% in the same period (Fig. 6-1).

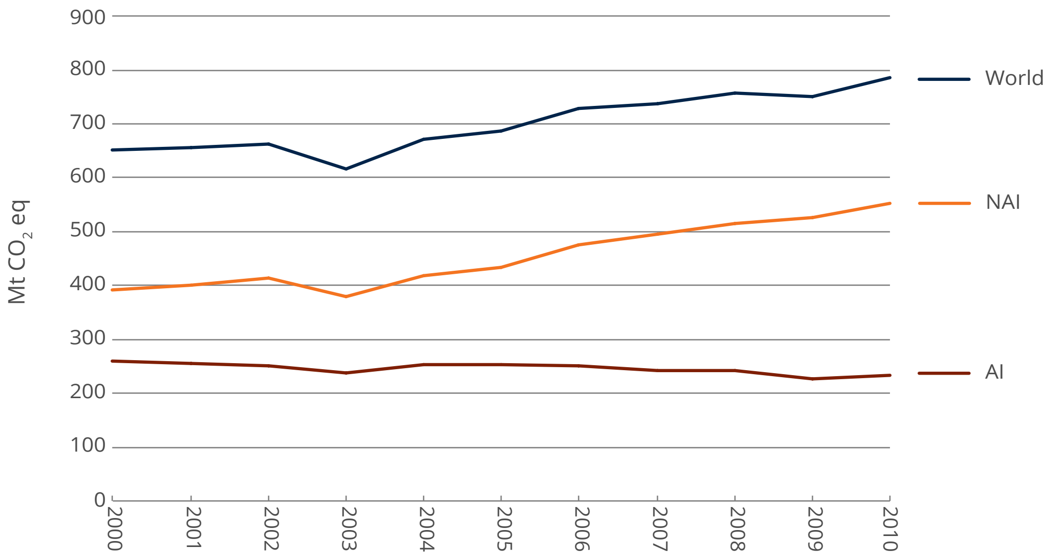


FIGURE 6-1 Historical trends in emissions from energy use, 2000-2010.

2000-2010 Trends: by Continent

Asia was the largest contributor (58%), followed by Europe (20%), the Americas (17%) and Africa (4%) (Fig. 6-2.a). Annual average emissions growth rates over the same period were greater in Africa (9.2% yr^{-1}), followed by Asia (3.2% yr^{-1}), while they were negative in Europe (-1.8% yr^{-1}) (Fig. 6-2.b). The Americas overtook Europe as the second largest emitter in 2010.

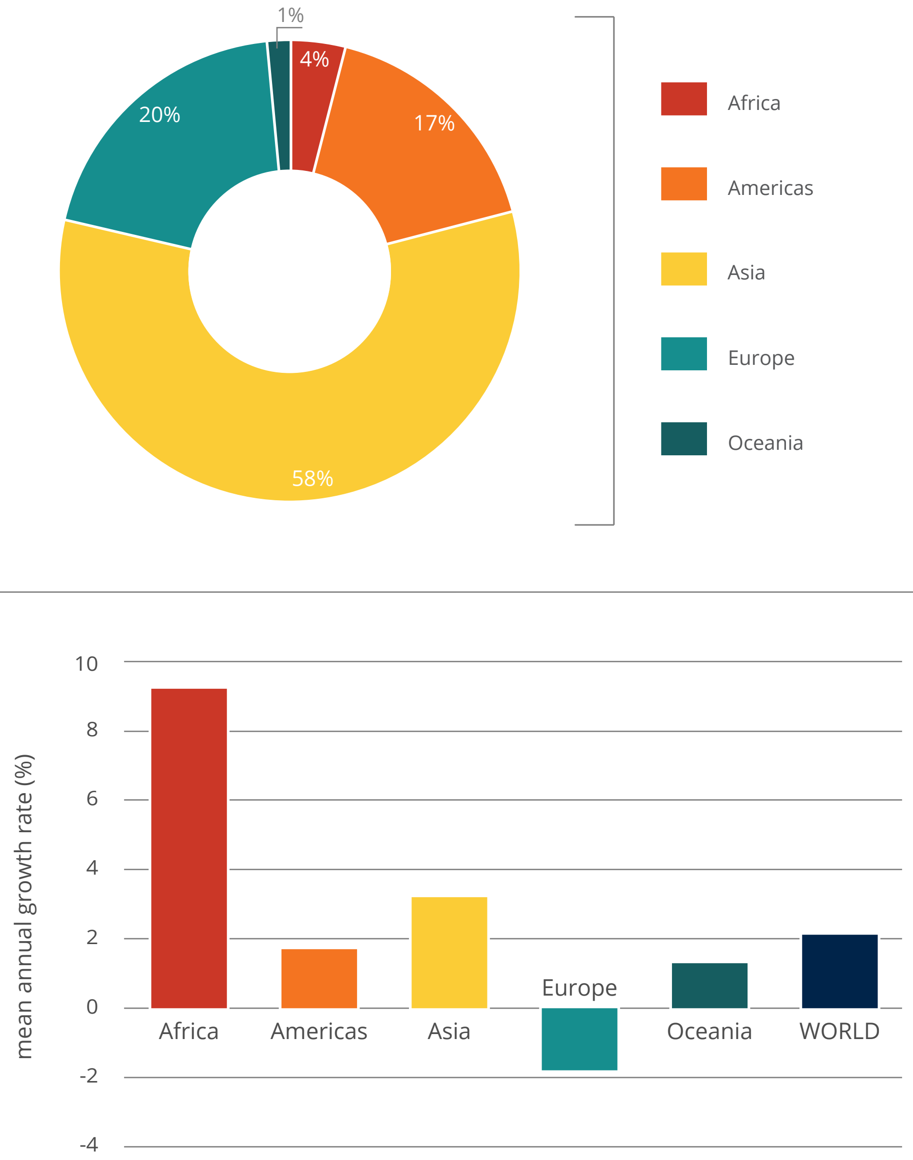


FIGURE 6-2 Energy use, 2000-2010: (a) emissions and (b) annual growth rates, by continent.

2000-2010 Trends: Energy carriers

Emissions from energy use were dominated by diesel, contributing 47% of all energy carriers considered (3% of which used in fisheries), followed by electricity (38%), coal (8%) and natural gas (3%) (Fig. 6-3). Estimates of emissions from power irrigation increased over 40% over this period, accounting for 26% of the total in 2010.

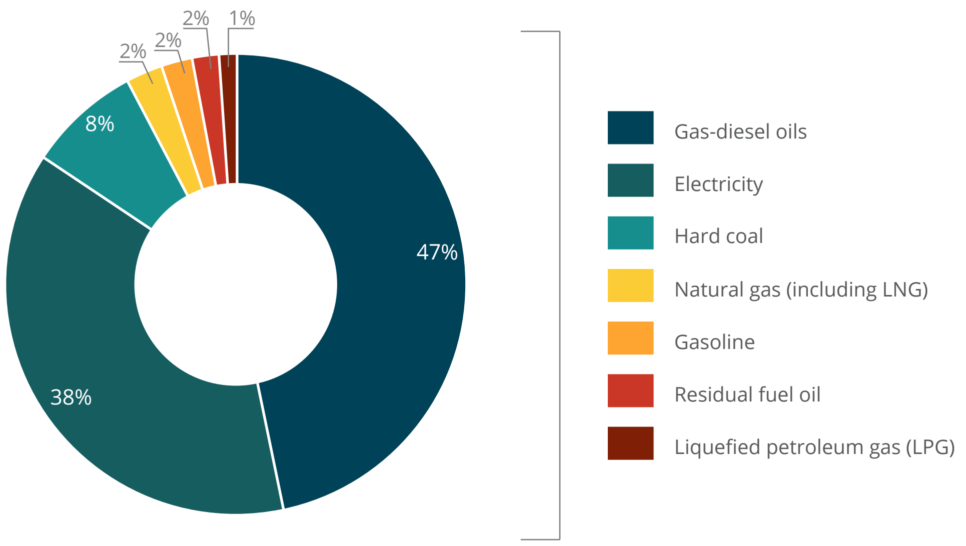
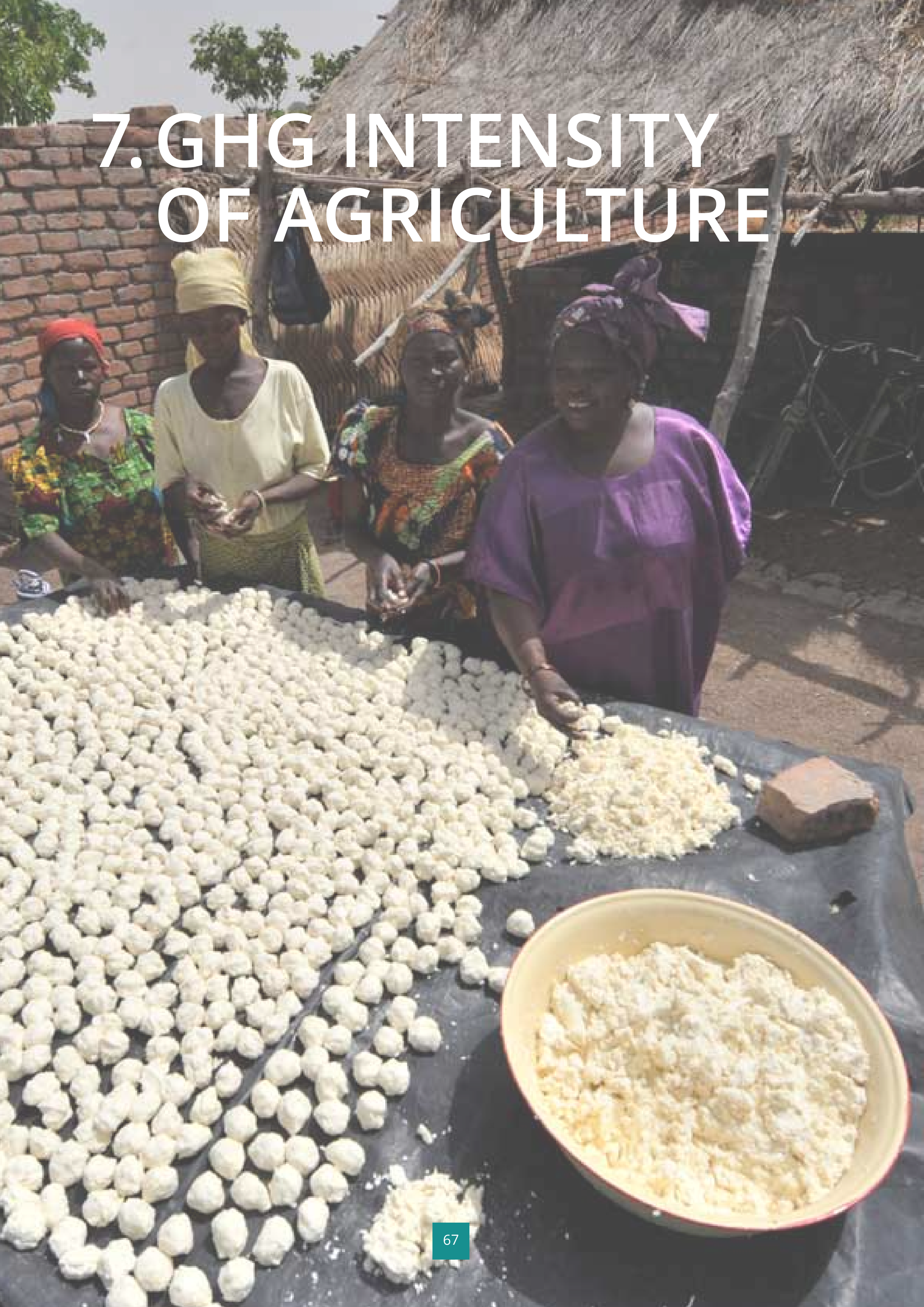


FIGURE 6-3 Energy use by energy carrier, 2000-2010.

TABLE 6-1 Energy use emissions by decade and in 2010 (Mt CO_2 eq)

Countries	1990s	2000s	2010
AI	285	247	232
NAI	342	445	553
World	627	692	785

7. GHG INTENSITY OF AGRICULTURE



Emissions of CO_2 eq can be expressed as a function of production of their underlying agricultural commodities. The FAOSTAT Emissions database allows for development of coherent indicators to this end, since the commodity production statistics that are necessary to compute such indexes are consistent with the same underlying activity data used in emissions estimation. Indicators shown herein provide a first set for analysis. Expressing GHG intensity, i.e., GHG emissions per unit commodity, for cattle meat and milk, pork meat, chicken meat and eggs, rice and other cereals. The GHG intensity indicators were computed for each country over the period 1961-2011, and then aggregated at regional and global levels. GHG emissions considered were only those within the farm gate, i.e., they are not full life-cycle assessments. Emissions estimates used for livestock products included enteric fermentation, manure management, manure left on pasture and manure applied to soils; emissions estimates used for rice were methane from paddy fields and nitrous oxide from fertilizer use. Emissions estimates used for other cereals were limited to nitrous oxide from fertilizer use.

1961-2010: Global Trends

In all decades considered, the GHG intensity values of the commodity products considered herein ranked from highest to lowest as follows: cattle meat, pig meat, eggs, rice, milk, and cereals.

Significant improvements (i.e., decreases) in GHG intensity of products occurred over the over the period 1961-2010. Specifically, GHG intensity of eggs decreased by -57%; rice by -49%; pig meat by -45%; milk by -38%; and GHG intensity of cattle meat decreased by -27%. By contrast, GHG intensity of other main cereals (wheat, maize), although maintaining the lowest GHG intensity over time for all the commodities considered, increased over the same period by 45% (Fig. 7-1).

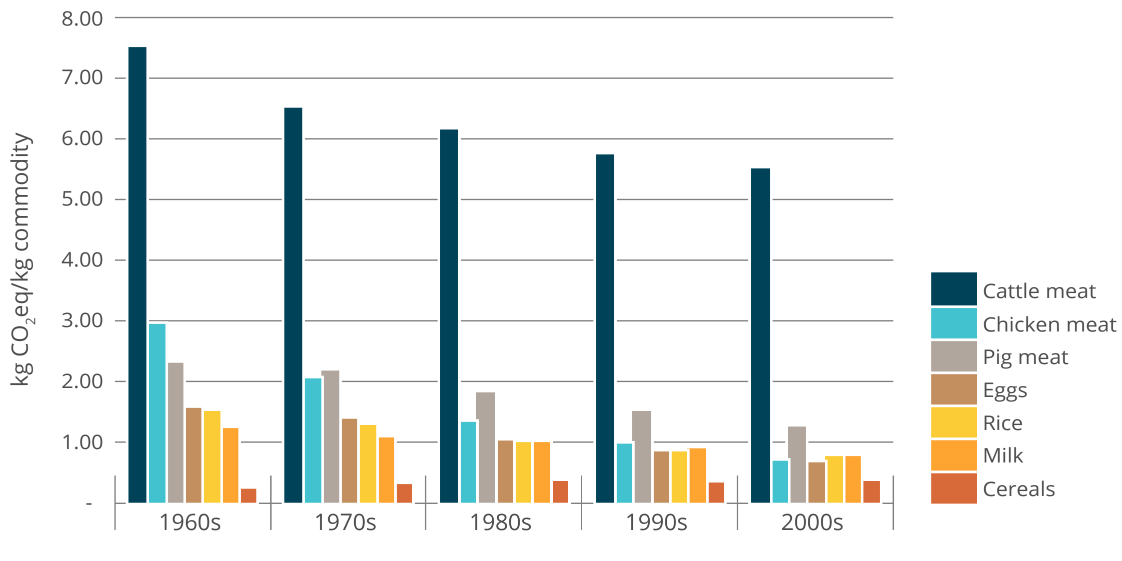


FIGURE 7-1 Historical trends in GHG emission intensity, by commodity, 1961-2010.

1961-2010 Data structure: GHG Intensity and Land and Livestock Productivity

The observed decreases in GHG intensity of commodities can be plotted against productivity increases of land and livestock outputs. Global values show an inverse relation between GHG intensity of a commodity product and their productivity across the commodities considered (Fig. 7.2).

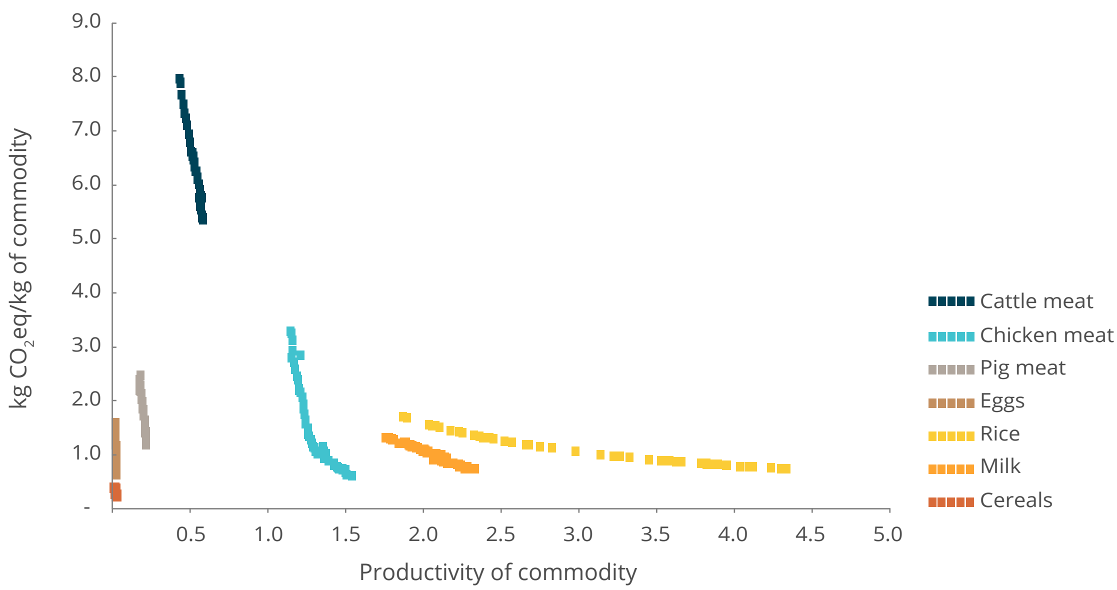


FIGURE 7-2 GHG intensity and productivity of commodities, 1961-2010.

This result –confirming previous findings of studies that included a fuller life-cycle analysis and applied higher tier IPCC emission factors (i.e., FAO, 2013a)—is due to the evolution from less to more intensive livestock production systems, resulting in increases in commodity output per animal or per unit land that are larger than the corresponding increases in emissions per animal or per unit land area. This relationship has great importance towards identification of mitigation strategies to be implemented in coming decades, but it should not be taken to mean that under all circumstanced, intensification of production is per se a mitigation strategy at national scale. Unless the underlying technical efficiency gains are implemented within the same economies of scale, well-known rebound effects may in fact result in more, rather than less, absolute GHG emissions, as well documented by the data over the 1961-2010 period. The challenge for the coming decades is therefore to find effective ways to decouple the observed historical trends, ensuring that further efficiency gains can lead to reduced absolute emissions.

8. CONCLUSIONS

This report presents a complete analysis of results of an expanded FAOSTAT Emissions database, providing a complete and coherent time-series of emission estimates for AFOLU and energy use in agriculture including fisheries. The data are provided at country-level, based largely on FAOSTAT and FRA activity data communicated by countries and IPCC 2006 Tier 1 methodology (IPCC, 2006). The exception for the source of activity data is for emission estimates that require geo-spatial information (via mapping and remote sensing analyses)—such as emissions from organic soils and biomass burning outside agriculture—which is usually not reported to FAO as a national statistics. IEA is used as a source of energy use in the agriculture sectors including fisheries. The data are automatically updated as the underlying FAO activity data are published. Data are currently provided over the following reference periods: Agriculture, 1961-2011; Land use, land use change and forestry, 1990-2010; Energy use in agriculture, 1970-2010.

The analysis provided indicate that AFOLU emissions continue to increase, but not as fast as emissions from fossil fuels, meaning that the contribution of AFOLU emissions to the total from all human activities is decreasing over time. Agricultural GHG emissions from all sources are increasing, with some faster than others. For example, for the period 2001-2011 emissions from synthetic fertilizer application are growing much faster (3.5%) than the other categories. Indeed, synthetic fertilizers may become the second largest emission source after enteric fermentation over the next decade, if increases continue at present rates. On the contrary, deforestation emissions are declining.

In terms of difference between regions, agricultural emissions in non-Annex I countries are increasing at a faster rate than those in Annex I countries, with some regions showing declines.

The database provides important information on the key sources of emissions from the AFOLU sector, the regions in which they occur and their rates of change, helping to identify hotspots for mitigation action. Recognizing that countries report their emission data to the UNFCCC with a range of nationally-validated approaches, the FAOSTAT Emissions database, because of the knowledge base it provides within a coherent data framework, represents a useful tool for data quality control/quality assurance, aimed at helping countries fill data gaps and improve data analysis, providing for the agriculture, forestry and other land use sector the same emission data analysis support as the IEA database currently provides for the energy sector.

Indeed, the FAOSTAT Emissions database is increasingly used as a tool by member countries in support of their need to identify, assess and report their GHG emissions from AFOLU. It was presented and discussed with representatives of nearly one hundred member countries through three regional workshops, held ahead of FAO Regional Commissions on Agricultural Statistics, and received formal endorsements from the Regional Commissions (APCAS, Vietnam, Oct 2012; IICA, Trinidad and Tobago, Jun 2013; AFCAS, Morocco, Dec 2013) (FAO, 2013; 2014). Furthermore, the FAOSTAT Emissions database is increasingly used by FAO and other international agencies for in-country work, i.e., as a tool in both non-Annex I and Annex I countries, providing support to member countries' GHG inventory needs related to UNFCCC, such as National Communications, Biennial Update Reports, and development of Nationally Appropriate Mitigation Actions (NAMAs).

The FAOSTAT emissions data are integral part of the new AFOLU emissions analysis of the IPCC Fifth Assessment Report (AR5), and thus contribute to the global knowledge base needed for an improved understanding of the role that agriculture, forestry and other land use activities can play under current and future international climate agreements towards limiting dangerous anthropogenic interference with the climate system.

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This report discusses new knowledge on anthropogenic greenhouse gas (GHG) emissions from agriculture, forestry and other land use (AFOLU) activities made available through the new FAOSTAT Emission database. The database is available globally, with country detail, for all agriculture, forestry and land sub-categories available in FAOSTAT and in the Forest Resources Assessment (FRA). GHG emissions are computed from official national activity data and geo-spatial analyses, applying international standard methodologies of the Intergovernmental Panel on Climate Change (IPCC) to ensure consistency with GHG Inventory processes established under the climate convention. The analysis shows increases in emissions of agriculture (from 4.6 to 5.0 Gt CO_2 eq yr^{-1} in 1990s and 2000s; 5.3 Gt CO_2 eq yr^{-1} in 2011), decreases in deforestation rates (from 4.6 to 3.8 Gt CO_2 eq yr^{-1} in 1990s and 2000s; 3.7 Gt CO_2 eq yr^{-1} in 2010), and decreases in forest sinks, albeit with a reversal since the mid-2000s (from -2,9 to -1.9 Gt CO_2 eq yr^{-1} in 1990s and 2000s values; -2.1 Gt CO_2 eq yr^{-1} in 2010). At the same time, the data show that GHG intensity of products (i.e., GHG emissions per unit commodity produced) decreased during 1990-2010, but that if no further mitigation measures and technical efficiency improvements are implemented, future emissions may further increase by up to 30% by 2050. Better information on AFOLU emissions is critical in many developing countries, given the potential to identify and fund actions that can usefully bridge national food security, resilience, mitigation and development goals into one coherent package.



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