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Environmental Statistics: New database on GHG emissions from agriculture and agri-environmental indicators

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ABSTRACT

The demand and need for data and information on agri-environmental indicators for use in analysis, planning and policy making, including greenhouse gas (GHG) emissions and mitigation potentials, continues to grow. One such need is for the annual inventories of GHG emissions and removals related to the agriculture sectors (crop and livestock production, forestry and fisheries, and associated land use changes), which countries need to submit periodically to the United Nation Framework Convention on Climate Change (UNFCCC). The data needed for this reporting present a unique challenge to inventory compilers, especially for developing countries, due to the scarcity of national data as well as technical capacity to monitor, collect and analyze relevant information. FAO, having a central role in the international arena with respect to matters related to agriculture, and leveraging on its significant experience and ability to undertake global assessments, has a fundamental role in meeting these new and increasing user needs. In addition, FAO has long maintained global datasets on agriculture and forestry that constitute an extremely valuable resource for compilation of GHG inventories. This paper reviews and highlights the most critical areas related to GHG agricultural emission data and presents the work FAO is currently undertaking to strengthen countries ability to gather, compile and analyze GHG related data, including a presentation of its first global assessment of GHG emissions from agriculture. Such efforts are necessary for gauging the mitigation potential of

different farming practices and methodologies and analysis procedures. The results of this work being undertaken in FAO will directly contribute to the Global Strategy to Improve Agricultural and Rural Statistics, the System of Environmental and Economic Accounts (SEEA), the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report, as well as support countries in UNFCCC negotiation processes, as they are necessary to produce the emissions reference levels needed to allow agriculture to access climate change financing mechanisms. This paper highlights these major challenges and provides solutions for filling data gaps and support for national inventory compilers and other stakeholders, highlighting the co-benefits of improved estimates in GHG assessments for the agricultural sector within development strategies aimed at improving food security, enhancing resilience of production systems and communities, while responding to climate change challenges.

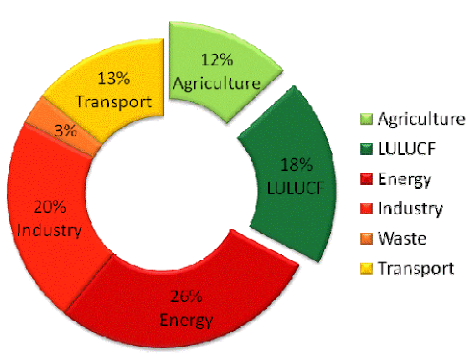
Keywords: Agriculture, Greenhouse gas, Emissions, Agri-environmental Indicators, Database

1. Introduction

The agricultural sectors face increased environmental challenges linked to new production methods and intensified production systems needed to meet continued population growth and new energy demands around the world. The artificial inputs of energy, chemical products, and agricultural labour necessary to increase as well as sustain long-term agro-ecosystem production inevitably alters natural biogeochemical cycles, leading to serious environmental damages, including soil degradation; soil and water pollution; biodiversity loss; increased greenhouse gases emissions and disruption of carbon sinks. Such negative pressures increase in coming decades towards 2050, as the global population continues to grow towards nine billion.

In particular, climate change presents unique challenges to agriculture. Global anthropogenic greenhouse gas (GHG) emissions, standing today at over fifty billion tCO_2eq (tonnes of carbon dioxide equivalents) annually and growing in tandem with energy use, are altering atmospheric concentrations well beyond natural levels. Current atmospheric CO_2 has surpassed 390 ppm, or about 35% above the pre-industrial equilibrium. Perhaps even more importantly, the rates of GHG increase in the atmosphere are much faster than those underlying natural cycles. Agriculture is both a major culprit as well as a potential victim to the ensuing climate changes. On the one hand, it emits close to 30% of total anthropogenic emissions globally, through land management activities for crop cultivation and livestock production, as well as through associated land use changes, including deforestation and degradation of organic soils. On the other, agriculture stands to suffer more than other sectors the combination of warming temperatures and increased frequency and intensity of extreme weather events that are associated to the climate change regimes predicted for of coming decades. At the same time, the global environmental impact of agriculture includes several dimensions beyond climate change, modifying natural cycles of water (irrigation withdrawals represent two-thirds of the total human use of freshwater resources), nitrogen (large watershed areas and river deltas are currently affected by eutrophication from algal blooms) and soils (erosion, desertification, dust) globally.

Figure 1. Anthropogenic emissions from all human sectors.



Countries have thus committed, within the United Nation Framework Convention on Climate Change (UNFCCC), to a reduction of their GHG emissions over coming decades, with OECD countries—so called Annex I parties to the convention, with developing countries listed as non-Annex I parties—having initially focuses via the Kyoto Protocol (KP) on reducing their GHG emissions to below 5% of 1990 levels in the commitment period of 2008-2012. Agriculture plays a major role in the global GHG budget, as discussed, and thus UNFCCC parties pay increasing attention to this sector in terms of helping them achieve their reduction commitments, especially in view of renewed attention to this sector in the climate policy agreements for the post-2012 commitment period. In fact, looking at the three major GHG gases, agriculture emits about one-quarter of global anthropogenic emissions of carbon dioxide (CO_2), over half of methane (CH_4), and two-thirds of nitrous oxide (N_2O). Emissions of CO_2 are dominated by deforestation (20%), with a small component from energy and machinery use (5%); emissions of methane are dominated by livestock production and rice cultivation; while emissions of N_2O are dominated by use of industrially produced inorganic fertilizer and animal manure applications to soils and pastures. Overall, livestock and feed production—including their role as a major driver for deforestation—are the largest contributors to anthropogenic GHG emissions from agriculture, producing about three-quarters of the total forcing.

In this context, adoption of better environmentally-sustainable production methods, as well as a focus on increased efficiency of resource use—especially soil, water and genetic resources for crops and livestock— is a major objective towards identifying the mitigation potential of GHG agricultural emissions, one that countries can use to plan their reduction commitments now and in coming decades. Such focus, importantly, lends to many synergies with and reinforces current rural development needs, considering that massive increases in agricultural production are often achieved at the expense of the surrounding environment[1]. In particular, many climate change mitigation strategies in agriculture tend to positively reinforce food security needs, by leading to better climate-adapted production systems with enhanced resilience, and by focusing on production solutions that create employment opportunities and respect local communities. The Intergovernmental Panel on Climate Change (IPCC) reports periodically on both the state of the science needed for identifying mitigation potentials around the world as well as provides guidelines for assessing, measuring and reporting GHG emissions, including from agriculture and related land use changes. In particular, IPCC Guidelines provide the methodological guidance to countries for reporting their annual inventories of greenhouse gas emissions and removals to the UNFCCC. The methods contained in the IPCC Guidelines differ in their complexity ranging from the simplest Tier 1 method, based on globally or regionally applicable default parameters, through Tier 2 methods based on country specific data, to Tier 3 methods involving more detailed modelling and/or inventory-based approaches for sub-national, including geo-referenced, information. The IPCC emission category Agriculture, Forestry and Other Land Use (AFOLU) presents a unique challenge to inventory- compilers, especially from developing countries, due to the lack of national data and the difficulty to monitor and update regularly land use and land use change statistics. Importantly, until recently developed countries were allowed to report their emissions to UNFCCC at intervals that depended on their national circumstances and capacity; however starting in 2014, they will be asked to report biannually their GHG emissions to the UNFCCC.

In addition, the most recent IPCC assessment report (2007) indicated many options for GHG mitigation in agriculture: from more efficient use and timing of chemical fertilizer to reduce N_2O emissions; to improvements to animal waste management systems and changes in animal diets to reduce methane emissions; to improvement in soil management techniques and land conservation—including reduced rates of deforestation, forest and grassland degradation. The challenges ahead lie in identifying specific subsets of such activities that are appropriate within the specific regional and socio-economic contexts of countries; quantify the associated GHG emission reductions; and finally, with particular attention to developing countries and especially least developed countries (LDCs), assess needs and gaps to design and implement effective project activities; assess and design monitoring and reporting needs and gaps; and investigate potential for regional scaling up.

Agri-environmental statistics and indicators, GHG emissions databases and environmental accounting frameworks are essential components of this strategy. They serve to assess, quantify and monitor the environmental performance of the different countries, and in particular UNFCCC non-Annex I parties, with a focus on measurements of absolute levels of agriculture-related GHG emissions including their trends, as well as identification of mitigation potential. In particular, robust and internationally recognized information tools and methodologies are needed to support climate change negotiation and associated funding processes. Such efforts are especially useful when linked directly to the IPCC process, which represents the technical and scientific reference of the UNFCCC Conference of Parties/Meeting of Parties to the Kyoto Protocol (COP-MOP) through its Scientific Body for Technology Advice (SBSTA). This is because climate financing to developing countries will be increasingly structured within regional climate response activity programs, such as Nationally Appropriate Mitigation Actions (NAMAs), based on sound science and monitored via a set of internationally accepted performance indicators. More in general, and in relation

[1] See, e.g., FAO 2011 "Linking sustainability, climate finance and the green economy in agriculture."

to the recognized linkages among sustainability, climate financing and the green economy, GHG-related information tools are complementary to—and in fact can often be derived within—rural statistics efforts, helping to further support policies towards effective incentive structures for sustainable management of natural resources, ensuring that national agricultural practices are developed and implemented within a holistic approach.

The FAO Statistics Division is currently working on the inclusion of relevant environmental data and indicators within the FAOSTAT[2] database. At present, FAOSTAT contains global coverage of integrated and compatible time series of statistics for about 200 countries covering agricultural production, prices, trade, forestry, fisheries, land use and agricultural inputs, etc. FAOSTAT has traditionally been focused on the production and trade aspects of food and agriculture for food security. In recent years with environmental issues being raised higher up the agenda, more emphasis has been placed on the datasets and indicators related to the environment has led to the development of an Agri-environmental domain in FAOSTAT due to be disseminated by the end of 2012.

Such efforts provide an effective leverage towards building a GHG central repository for agriculture, coherent with IPCC and UNFCCC goals. Indeed, FAO has long maintained global datasets on agriculture and forestry that constitute an extremely valuable resource for compilation of inventories of greenhouse gas (GHG) for the AFOLU sector as noted in the IPCC Guidelines. However, these datasets cater to a wide range of information needs and may differ from the data required for GHG compilation in certain key respects. In addition, GHG related data are needed by an ever increasing stakeholder community, for a number of purposes[3]. Assessing the environmental impact of agricultural products through life-cycle assessments, for example, is becoming a key requirement in both the public and private sectors. To meet the new needs of stakeholders requires a broader set of data at a finer resolution. This paper investigates the unique set of challenges and opportunities towards the development and compilation of GHG-relevant agriculture environmental indicators (AEIs) at FAO, addressing assessment needs and gaps of developing countries and especially LDCs—but also focusing on key scientific needs that create equal challenges to developed countries as well. We first identify data that is already available for use in the preparation of UNFCCC compliant GHG national inventories, and links to access the data with relevant metadata are provided in the report. This paper further identifies major data gaps in estimating GHG emissions and calculating the mitigation potential of the agriculture, forestry and other land-use (AFOLU) sectors.

2. Environmental Statistics and Indicators

Within the context of the environmental challenges and opportunities for agriculture within the climate change problem, agri-environmental statistics and indicators are required to play key roles: they help analysts and policy makers better understand the nature and magnitude of future risks and benefits related to mitigation activities, in particular in conjunction with food security and other key rural development goals; they facilitate the analysis of causes and interactions of environmental issues as a function of climate policy; and finally, they provide the quantitative background needed to monitoring and reporting GHG emissions within an internationally accepted framework for use towards rewarding through climate finance effective mitigation responses in agriculture, including through NAMAs.

In this context, the FAO Statistics Division is preparing a multidisciplinary agri-environmental dataset composed by environmental data from the thematic databases already available at FAO or from other institutions (both statistics and geospatial datasets) and derived agri-environmental indicators to further expand the domains covered by FAOSTAT. Agri-environmental indicators (AEIs) are indicators able to describe and assess state and trends in the environmental performance of agriculture in order to furnish useful indications to scientists and policymakers about the state of the environment, about the effects of different policies, as well as about the efficiency in the use of

[2] http://faostat.fao.org

[3] Two major expert meetings were held at FAO to help identify emerging needs in GHG data gathering, analysis and reporting. See for instance: http://foris.fao.org/static/data/nrc/IPCC-FAO_IFAD_Meetingreport20100423FINAL.pdf; www.fao.org/climatechange/59239/en/

budgets in terms of environmental outcomes. AEIs have ideally to be robust, timely, simple, and relevant to the different stakeholders involved in agriculture.

In general, the main constraint in the operational use of AEIs, including for GHG assessment, is the lack of reliable data, limiting the number of indicators that can be actually regularly produced. The statistical methodological development of the AEI framework has been led by the OECD[4] and EUROSTAT[5]. The FAOSTAT Agri-environmental domain has been developed in coordination with the OECD and EUROSTAT frameworks, in order to gain from the theoretical background already developed by these institutions with the aim of extending the geographical coverage of OECD and EUROSTAT AEIs to the rest of FAO member countries as available.

The definition of the FAO AEIs framework and the coordination with the existing frameworks presented above had to face challenges arising from limited data availability. While OECD and EUROSTAT designed their frameworks primarily over a limited number of Developed Countries (OECD countries and European Union member states), with established and solid structures in charge of data collection, in the case of FAO the area of interest covers virtually all the globe, and there are great differences in the amount of data available in the different countries and regions.
The FAOSTAT Agri-environmental domain under development includes 19 indicators, described by 68 data series. For agri-environmental statistics, the FAO Statistics Division collects and disseminates data based on the:

- Land use questionnaire, which includes the following categories: Country area (including area under inland water bodies), Land area (excluding area under inland water bodies), Agricultural area, Arable land and Permanent crops, Arable land, Temporary crops, Temporary meadows and pastures, Fallow land (temporary: less than 5 years), Permanent crops, Permanent meadows and pastures, Forest area, Other wooded land, Other land covering the country as a whole. Data are also available on Area equipped for irrigation, etc.

- Fertilizer questionnaire requests official data on production, trade and use for crop production. The information presented represents a broad picture of the situation regarding official data gathered on fertilizers statistics.

- Pesticides questionnaire requests data on consumption for major groups of pesticides (insecticides, herbicides, fungicides, plant growth regulators and rodenticides) and seed treatments.

These indicators are shown in Table.1, including relevant direct and indirect linkage to the assessment of GHG emissions and mitigation potential.

Table 1. Agri-environmental indicators under development within FAOSTAT, including linkages to GHG assessment. AOLU, REDD+ refers to mitigation via biological C-sequestration above and below ground.

Domain	Subdomain	Indicator	GHG Link
Responses	Land	Agri-environmental commitments	AFOLU, REDD+
		Organic agriculture	N_2O
Driving forces	Fertilizers	Mineral fertilizers consumption	N_2O

[4] OECD. 2001. Environmental Indicators for Agriculture. Vol. 3: Methods and Results. Paris: OECD. http://www.oecd.org/dataoecd/24/35/40680869.pdf
[5] European Commission. 2006. Development of agri-environmental indicators for monitoring the integration of environmental concerns into the common agricultural policy. Communication from the Commission to the Council and the Parliament. COM(2006) 508 final.
Eurostat, DG Agriculture, DG Environment, JRC, EEA. 2001. Towards agri-environmental indicators - Integrating statistical and administrative data with land cover information.Topic Report No. 6. Copenhagen: EEA. http://www.eea.europa.eu/publications/topic_report_2001_06

	Pesticides	Pesticides consumption	Energy CO_2
	Water	Area equipped for irrigation	Energy CO_2
	Energy	Energy use	Energy CO_2
	Land	Agricultural land use change	AFOLU, REDD+
		Share agricultural land	AFOLU, REDD+
		Cropping patterns	C-Sequestration
		Livestock patterns	CH_4, N_2O
		Conservation agriculture	Soil C
	Air & Climate Change	Ammonia emissions	CH_4, N_2O
Pressure	Nutrients	Gross Nitrogen Balance	N_2O
		Gross Phosphate Balance	CH_4, N_2O
	Air & Climate Change	GHG emissions from agriculture	Direct CO_2, CH_4, N_2O
	Water	Water use in agriculture	Soil C, CH_4, N_2O
	Soil	Soil erosion	Soil C
	Energy	Biofuel	AFOLU, REDD+
State	Soil	Soil quality	Soil C

2.1 Improving Environmental and GHG Data and indicators

A number of international activities on environment statistics are currently underway. The United Nations Statistical Commission [6] Forty-first session held 23-26 February 2010 and the Forty-second session in 2011 included a number of items on the environment. The agenda of the Commission included the following items on environment statistics: Report of the Secretary-General on the Framework for Environmental Statistics (E/CN.3/2010/9); Report of the Inter-secretariat Working Group on Environment Statistics (E/CN.3/2010/10) and Report of the Committee of Experts on Environmental-Economic Accounting (E/CN.3/2010/11). The Commission acknowledged that the United Nations Framework for the Development of Environment Statistics (FDES) had been a useful framework in many countries and endorsed the programme of work on the revision of the FDES. The Commission noted that the FDES provided a number of principles that should be followed in the revision process. In particular, the need to engage all stakeholders, including the scientific community and the need to ensure complementarity with the Handbook of National Accounting: Integrated Environmental and Economic Accounting (SEEA) 2003 was stressed. The third Expert Meeting on FDES[7] will be held in November 2011 with the expectation that a revised Framework for Environmental Statistics be presented to the United Nations Statistical Commission at the 2012 session.

The System of Environmental-Economic Accounts (SEEA)[8], currently under revision, will provide the internationally agreed conceptual framework to measure the interactions between the economy and the environment and the state of the environment. The revised SEEA will build upon its predecessors: the SEEA-2003 and the SEEA-1993. The revised SEEA is also expected to be present to the United Nations Statistical Commission at the 2012 session. At the sixth Meeting of the United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA) held in June 2011, a proposal for the development of a System of Environmental and Economic Accounting for Agriculture (SEEA-AGRI), was presented by FAO Statistics Division. Within this framework, agriculture is interpreted in the broad sense as all activities related to crops, livestock, forestry and fisheries. The development of the SEEA-AGRI will be led by FAO. FAO will seek technical assistance, where relevant, from the

[6] http://unstats.un.org/unsd/statcom/sc2010.htm and http://unstats.un.org/unsd/statcom/sc2011.htm
[7] http://unstats.un.org/unsd/environment/fdes/fdes_egm.htm
[8] http://unstats.un.org/unsd/envaccounting/ceea/meetings/UNCEEA-6-4.pdf

London Group[9]. The Committee agreed that the concept of SEEA-AGRI is of high importance. The Committee welcomed the willingness of FAO to lead the work on this subsystem of the SEEA, noting that agriculture together with forestry and fisheries make up a large portion of ecosystem services. It was suggested that SEEA-AGRI be used to help establish a hub between SEEA and the wealth of statistics available at FAO. The SEEA-AGRI will provide a statistical framework for countries to monitor key agri-environmental statistics such as GHG emissions.

The FAO Statistics Division Land use questionnaire (2011) for the first time included items on land-use change among all six IPCC land categories. The new items in the questionnaire include a land-use change matrix, whereby member countries are asked to not only report on the area extent of each of six land use categories, but also to attempt to relate information on the relative movements from one land category to another from year to year (for instance, land converted to agriculture from forest land).

In December 2009, FAO initiated a consultation process inviting experts and representatives from key institutions, including IPCC to review the state of knowledge on GHG emissions and mitigation potentials in the agriculture, forestry and fisheries sectors and to assess the need for monitoring and assessment of GHG cycle, emissions and mitigation potential in the agriculture, forestry and fisheries sectors. The consultation highlighted the need for a global assessment which would supplement and support existing monitoring/assessment frameworks (such as UNFCCC/IPCC and the FAO Global Forest Resources Assessment - FRA) and would contribute to ensuring robust data collection which meet a variety of needs, including policy design and implementation. The IPCC category Agriculture, Forestry and Other Land Use[10] (AFOLU) presents a unique challenge to the inventory compilers especially from developing countries due to the paucity of national data. FAO has long maintained global datasets on agriculture and forestry that constitute an extremely valuable resource for GHG inventories compilation for the AFOLU sector as noted in the IPCC Guidelines. However, these datasets cater to a wide range of information needs besides GHG inventory compilation and may differ from the data required for GHG compilation in certain key respects. Therefore, some additional guidance on the access to, and use of, these datasets beyond what is available in the IPCC Guidelines is useful for inventory compilation especially for developing countries and those with limited resources.

Within the general AIEs effort undergone at FAO, particular attention is being devoted to quantifying GHG emissions and mitigation potentials, with a goal to obtain synthetic and comprehensive assessments for the different countries, consistently with IPCC methodologies and UNFCCC requirements, and providing specific attention to the assessment, monitoring and reporting needs and gaps of LDCs. This activity is carried out within the project: "Monitoring and Assessment of GHG Emissions and Mitigation Potentials in Agriculture", within the Mitigation to Climate Change in Agriculture (MICCA) Programme[11]. Its first three years of activity are funded by the Norwegian and German Governments. Key project goals are as follows:

- Generate knowledge that can help developing countries identify mitigation options in agriculture, forestry and fisheries -consistently with their rural development goals, in particular reinforce food security and increase resilience of agro-ecosystems, resulting in better adapted production systems.
- Development of a FAO GHG database on emissions and mitigation potentials, to support countries UNFCCC reporting goals, as well as providing a guideline to identify national mitigation goals and strategies, including NAMAs.
- Close collaboration with IPCC and UNFCCC in support of negotiations

[9] http://unstats.un.org/unsd/envaccounting/workshops.asp?fType=2&mType=L

[10] AFOLU Agriculture Forestry and Other Land Use *(AFOLU) sector of 2006 IPCC Guidelines and* Agriculture *and* Land Use, Land Use Change and Forestry (LULUCF)/Land Use Change and Forestry (LUCF) *of the* GPG *and* GPG-LULUCF/1996 IPCC Guidelines.

[11] http://www.fao.org/climatechange/micca/en/

3. Assessing GHG Emissions from Agriculture

The FAO Monitoring and Assessment of GHG Emissions and Mitigation Potential Project (MAGHG) supports as discussed the inclusion of GHG statistics within the FAOSTAT efforts to develop agri-environmental indicators. The project aims at strengthening FAO and member countries' ability to gather, compile and analyse their GHG statistics and the underlying activity data. To this end, it has recently developed a first global assessment of GHG emissions from the agricultural sectors. The data and feedback from member countries will form the basis for gauging the mitigation potential of different farming practices and methodologies; identifying economically viable and sustainable practices; building international consensus and developing guidelines on data, metadata and analysis procedures (for example for life cycle analysis – LCA). The results will directly contribute to the IPCC fifth assessment report, as well as to the ongoing efforts on revising IPCC GHG reporting guidelines, thus supporting the UNFCCC negotiation process by helping to produce the baseline emission data needed to allow agriculture to access climate change financing mechanisms.

A preliminary activity of the MAGHG project was to link directly with IPCC at the outset of its activities, to jointly analyze needs and gaps towards improving GHG data collection and reporting activities, highlighting information gaps in the data and providing key recommendations. IPCC needs include the following. With regards to enhancing measurements and reporting related to land use statistics:

- More consistent and transparent global definition of forest;
- Improvements in National inventory and country statistics;
- Standardisation of methodology used to collect forestry information;
- Extensive surveys in tropical biomes of the different C pools;
- Submission of the geographic location of where LUC is occurring;
- Information on the fate of harvested wood products;
- Analysis of forest management practices;

With regards to improving global estimates from agriculture:

- Increase in the frequency of submission or increase in the number of years National Communications submitted by non–Annex I countries;
- Commitment to develop country specific emission factors, i.e., higher tiers for calculating emissions;
- Provide a coherent data platform that can be used for benchmarking national communication and strengthen their communication to the international community and UNFCCC.

With regards to mitigation strategies:

- Increase in the number of studies investigating the mitigation potential of agro–forestry in tropical regions;
- Increase in the number of studies investigating the mitigation potential of grasslands;
- Increase in the number of studies of the mitigation of methane and nitrous oxide for croplands and grasslands and also the management of organic soils;
- Improvement in reporting of annual national statistics of animal numbers and area under each land use type;

3.1 Data and Knowledge Gaps

During the preliminary consultations with IPCC, a number of key international data sources for GHG that are already computed, gathered and managed at FAO were identified. The key data sources relevant to AFOLU GHG data include:

- FAO, *Global Forest Resource Assessment* (FRA www.fao.org/forestry/fra);

- FAO, *National Forest and Monitoring Assessment* (NFMA www.fao.org/forestry/nfma/en/);
- FAO, Harmonized World Soil Database (HWSD http://www.fao.org/nr/water/news/soil-db.html);
- FAO, *Global Climate Maps* (www.fao.org/nr/climpag/climate/index_en.asp);
- FAO, *Global Planted Forests Thematic Study* (http://www.fao.org/forestry/plantedforests/10368/en/);
- FAO, *FAOSTAT* (http://faostat.fao.org/default.aspx)

Whilst major key data sources have been identified, there are still major data gaps and inconsistencies regarding requirements for countries for reporting their annual inventories of greenhouse gas emissions (GHG) and removals to the UNFCCC. International agricultural statistics have traditionally focused on issues relating to agricultural production, agricultural trade and food security. FAO has statistical datasets from the 1960's, which focus on agricultural production and trade (crops, livestock) in quantity and monetary terms. The statistical domain used to generate the key agricultural and food security indicators (such as production yields or the number of undernourished in a country) is well-established and have long time series of data for most countries. The FAOSTAT database was developed with this focus on agricultural production and food security and subsequently is structured to primarily suit these needs. Where there are key data gaps for producing indicators, such as production yields or the number of undernourished, considerable efforts are made to estimate data and to ensure these key indicators can be calculated.

At the national level, many country statistical systems are not yet designed for collecting data on parameters relevant for GHGs (which should be undertaken in a continuous and systematic way). Assessments such as life-cycle analysis, which requires information at each stage and for each input of production systems, is even more difficult to gather. Many countries need additional capacity and guidance on gathering this type of data, and incentives to release it. Emission factors and carbon stock factors are often available but need further development and validation. A number of general issues on the subject of data gaps were identified in the sessions and include:

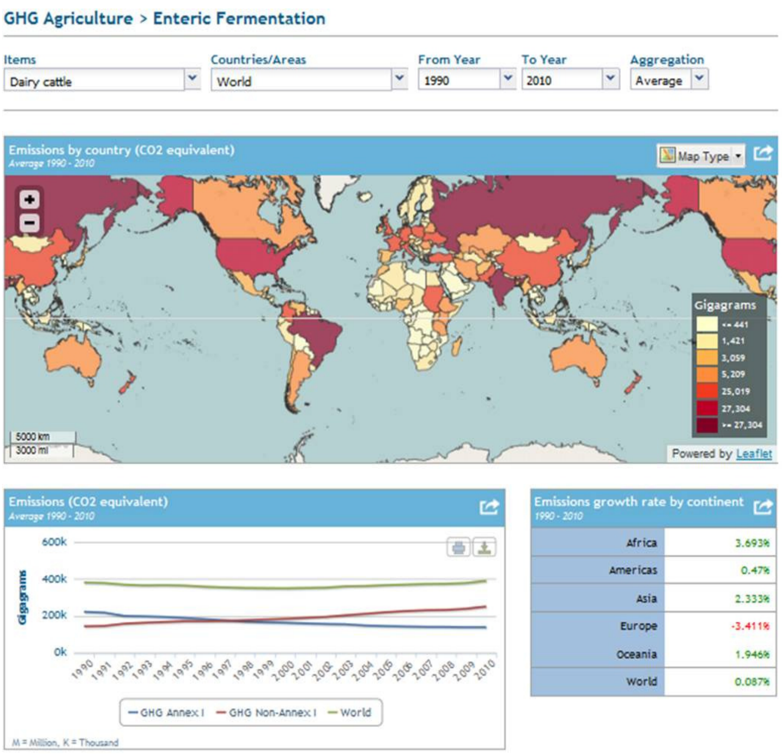
- Data gaps are particularly large in developing countries. Around 110 countries regularly report agricultural production-data to FAO. The non-reporting countries are unlikely to be in a position to start reporting in the short-term. Considerable investment in staff and resources is needed to improve this situation;
- Data quality generally has not been systematically assessed. It is therefore difficult to evaluate the quality of data within some national datasets;
- A lot of the data required is in private hands (particularly for the processing phase). The issue of confidential (commercial) data is one which is becoming more pressing for FAO, particularly in regard to production of various agri-environmental inputs such as fertilizers and pesticides;
- Some data is too aggregated, some too site-specific (particular for the processing phase, where figures might be plant-specific) – the right balance between practicality and accuracy is required in order to identify good and bad practices and reward improvements;
- Guidance is needed to deal with data gaps (estimation procedures etc.). Clear and consistent data imputation procedures need to be established and implemented in the various agri-environmental data domains;
- Baseline emissions factors from different farming systems need to be established and better descriptions of agricultural land management practices and their emission impacts are needed.

Specific Data Gaps include: (i) Emissions factors for nitrous oxide have large potential consequences but appropriate factors are currently scientifically uncertain. Data on the level of nitrous oxide from dispersed manure in rangeland systems is particularly lacking; (ii) Ruminant digestibility is a key area in need of more data for life-cycle assessments (LCA); (iii) A more systematic assessment of technologies and practices needs to be made; (iv) Improved estimation of carbon stocks and fluxes in the agricultural sector are required, especially regarding soil carbon (for example soil depth measurements); (v) Improved data is required for certain agro-ecological zones, production and cropping systems and soil dynamics, e.g. data is poor or missing for many tropical cropping systems and most grasslands, and many soil management responses are often poorly understood; (vi) A tree biomass database containing original tree biomass measurements and models would be very valuable; and (vii) Improved data on agricultural inputs (such as fertilizers), management practices and processing are required.

4. The FAOSTAT GHG Database

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 (*Montzka et al.*, 2011).

Figure 2. Computer screen view of the new FAOSTAT GHG database (FAO internal version; public release scheduled December 2012).



In order to compile a global GHG emissions database with regional detail, all three methods can and have been used (e.g., *IPCC 2006*; *Crutzen et al.*, 2007; *Montzka et al.* 2011). However, in order to address sectoral and regional contributions, including in particular with national level details, methods under ii) are unsuitable. For national-level reporting of GHG emissions to the UNFCCC, IPCC guidelines (*IPCC*, 1996, 2000, 2003, 2006) indeed endorse 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). FAO developed a global GHG emission database with country level detail, using activity data from the FAOSTAT database (*FAO*, 2012; see Fig. 2). The database is currently available only within FAO; it is currently undergoing peer-review and is scheduled for release by end of 2012.

These data (e.g., crop area, yield, livestock heads, etc.) are those collected by member countries, typically *via* National Agriculture Statistical Offices, and reported to FAO. 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. The database is used widely in peer-reviewed literature as the basis for a range of AFOLU-related analyses, from global agriculture perspective studies (e.g., *Foley et al.*, 2011) to land-use change assessments of importance to carbon cycle studies (i.e., *Friedlingstein et al.*, 2011).

Basic, standard IPCC default equations were applied for assessing bottom-up, country level GHG emissions. Using IPCC guidelines and a Tier 1 approach (*IPCC*, 2006) we computed, for each sector for which the needed AFOLU activity data were available in FAOSTAT:

$$GHG = EF*AD \qquad (1)$$

Where: GHG = greenhouse gas emissions; EF = Emission factor; and AD = activity data. This paper reports on GHG emission estimates already completed within FAOSTAT, for all agriculture sectors and for net forest

conversion, representing over 80-85% of total agriculture emissions and 66% of FOLU emissions reported by *IPCC* (2007). Emissions were computed for nearly 200 countries for the reference period 1961-2010, covering emissions of non-CO2 gases (CH_4 and N_2O) arising from enteric fermentation, manure management systems; synthetic fertilizers, manure applied to soils and left on pastures; crop residues; rice cultivation. In addition, we computed direct CO_2 emissions from net forest conversion, based on FAOSTAT land-use statistics and the Forest Resource Assessment (FRA) (*FAO*, 2010) data for the period 1990-2010.
Two critical FOLU emission categories—in terms of contribution to total AFOLU emissions, i.e., biomass burning and drained organic soils—were not directly estimated and are not currently part of the country-level GHG database presented herein. For one, they require information currently not available in FAOSTAT, as well as detailed spatial analyses beyond a simple Tier 1 approach. Secondly, the input data for analysis that are available in the literature are sparse and quite uncertain (e.g., *Hougthon et al.*, 2012). In order to compare our results to other global estimates, we made nonetheless the following rough global estimates for the period 2000-2010. We estimated global non-CO_2 emissions from drained organic soils used for agriculture to be in the range 0.2-0.4 $GtCO_2eq\ yr^{-1}$ for the period 2000-2010, based on area of drained organic soils recently reported by FAO (2012) and the relevant IPCC Tier 1 emission factors. We estimated global biomass burning to be in the range 0.60-0.75 $GtCO_2eq\ yr^{-1}$ for the period 2000-2010, in line with recent estimates (*Houghton et al.*, 2012), by simply using the 2005 IPCC AR4 data (*Smith et al.*, 2007) relative to the share of biomass burning emissions to the agriculture total, as well as the total emission estimates (i.e., 12% of 5.1-6.1 $GtCO_2eq\ yr^{-1}$).

4.1 Results

The GHG emission data presented herein cover the period 1961-2010, at country level, based on a single, coherent computational platform that links activity data to emissions, based on FAOSTAT analyses and IPCC guidelines. This paper focuses on analyses of temporal trends, regional dynamics and comparisons (Fig. 3). An online version of the FAOSTAT GHG database, allowing for full country level analysis, is nearing completion and will be released before the end of 2012. It is noted that the FAOSTAT GHG database is not a replacement for UNFCCC reporting of its member countries. Rather, the database aims at supporting the international scientific community by providing continuous updates of emission trends from AFOLU sectors, and by providing FAO member countries with a coherent framework for analyses of their emissions baselines and future trends, including the ability to comparisons across regions and over long time periods, consistently with their internationally reported activity data.

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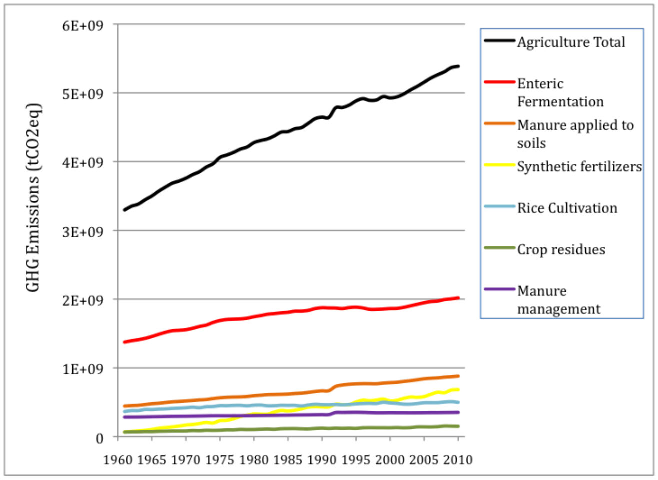
Global and Regional Trends in Agriculture Emissions

Global GHG annual agriculture emissions increased on average by 1.6% per year from 1961 to 2010, reaching 4.6 $GtCO_2\ yr^{-1}$ in 2010 for the categories computed herein (and up to 5.4-5.8 $GtCO_2\ yr^{-1}$ in 2010, with emissions from biomass burning and organic soils included). Over the same period, crop, milk and meat production increased on average 2.2%-6.4% annually (*FAO*, 2012), implying a significant improvement—up to three times better—in the carbon intensity of agricultural production. At the same time, carbon emissions from fossil fuel and cement manufacture increased at more than three times the rate of those from agriculture, on average 5.2% annually (*CDIAC*, 2012).

Figure 3. Global trends in GHG emissions by sector, 1961-2010, based on FAOSTAT activity data.



In 2010, as during the period 2005-2010, the largest contributors to agriculture emissions computed within the database were enteric fermentation (38%), manure left on pasture (14%), synthetic fertilizer (13%), biomass burning (11%), rice cultivation (9%), manure management systems (7%), N_2O emissions from organic soils (5%), crop residues (3%), and manure applied to cropland (2%) (Fig. 3). Different shares characterize each region in the analysis.

Under the UNFCCC reporting framework, N_2O emissions from agricultural soils, including emissions from synthetic fertilizers, manure and crop residues, is treated as a single reporting category. To this end, our estimates indicate a total contribution of 37% in 2010, similar to that of enteric fermentation. A number of alternative aggregations to those indicated by IPCC are possible. For instance, a category 'manure,' defined as the aggregate of emissions from manure left on pastures by grazing animals, manure applied to cropland as organic fertilizer, and manure treated in management systems, would represent in our database 23% of total emissions from agriculture. Importantly, a category 'livestock,' defined as the sum of emissions from enteric fermentation and manure emissions, plus emissions from cropland related to feed[12], would represent over 80% of total agriculture emissions, in line with recent estimates (*FAO*, 2008; *Leip et al.*, 2010), and highlighting the fact that emissions related to direct human consumption of food crops contribute only 20% of the total. We next offer a more detailed description of the major emission categories for agriculture.

Enteric Fermentation

Emissions from enteric fermentation were computed at Tier 1 level, using national-level statistics of animal numbers reported to FAOSTAT. Globally, emissions in this category grew from 1.3 to 2.0 $GtCO_2eq\ yr^{-1}$ during the period 1961-2010, with average annual growth rates of 0.95%. During the 1990's emission growth slowed down compared to the long-term average, but have picked up again since the year 2000. As shown in Fig. 2, enteric fermentation represented the largest contribution to agricultural emissions. In 2010, over 1.5 $GtCO_2eq\ yr^{-1}$ were emitted in developing countries, or 75% of the total. Averaged over the period 2000-2010, Asia and the Americas were the largest contributors (36% and 34% respectively), followed by Africa (14%) and Europe (12%). Emissions growth rates were largest in Africa, on average[13] 2.4% yr^{-1}. In both Asia and the Americas emissions grew at a slower pace (1-1.2% yr^{-1}), while they decreased in Europe (-1.7% yr^{-1}). Indeed, in 1990-2000 Europe's contribution to the total (17%) was larger than Africa's (11%). Over the period 2000-2010, emissions were dominated by cattle, responsible for three-fourths of the total (56% non-dairy cattle; 19% dairy cattle), followed by buffaloes (11%), sheep (6.8%) and goats (4.6%).

Manure

Emissions from manure N applied to cropland as organic fertilizer, left on pasture by grazing animals, or processed in manure management systems, were computed mostly at Tier 1 level, using statistics of animal numbers reported to FAOSTAT for estimating both 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; manure fractions disposed to different manure management systems; manure fractions 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. For CH_4 emissions, IPCC required a Tier 2 approach to estimate methane production rates from specific manure management systems as a function of average annual temperatures by country. To this end, agro-meteorological output from the FAO global agro-ecological zone model (*IIASA/FAO*, 2012) was aggregated to

[12]Computed as the ratio of feed to food for cereal production, or roughly 45% over 2005-2010 (FOASTAT, 2012)

[13] Regional values are reported statistically, as least-square growth rates.

obtain country-level mean annual temperature data. Global emissions from manure N applied to soils— organic fertilizer on cropland or left on pasture—grew during the period 1961-2010 from 0.44 to 0.88 $GtCO_2eq\ yr^{-1}$. Average annual growth rates were 2% yr^{-1}, with a slow-down in recent decades. Emissions from manure left on pasture dominated this emission category, as they were far larger than those from manure used on cropland as organic fertilizer (87% of the total in 2010; of which 80% in developing countries). During the period 2000-2010, the Americas (33%), Asia (31%) and Africa (25%) dominated this emission category. Growth rates over the same period were largest in Africa, on average 2.4% yr^{-1}. Emissions grew at a slower pace in both Asia and the Americas (1.2-1.7% yr^{-1}), while they decreased in Europe (-1.4% yr^{-1}). Grazing cattle was responsible for two-thirds of the total (53% non-dairy cattle; 11% dairy cattle), followed by sheep (12%) and goats (12%). By contrast, emissions from manure applied to cropland as organic fertilizer were larger in developed compared to developing countries in the period 2000-2010. Largest emitters were Europe (40%), Asia and Americas (28% each), while Africa represented a mere 3% of the total, albeit with robust growth rates of 3.4% yr^{-1}. Swine were the largest contributors (53%), followed by cattle (24% dairy cattle, 18% non-dairy cattle).

Compared to manure applied to soils, emissions from manure management grew more slowly, i.e., from 0.28 to 0.35 $GtCO_2eq\ yr^{-1}$ during the reference period 1961-2010, with average annual growth rates of only 0.5% yr^{-1}. Over the period 2000-2010, emissions were dominated by Asia (36%), Europe (30%) and the Americas (27%). Africa and Oceania emitted each only 3-4% of the total.

Synthetic Fertilizer

Emissions from use of synthetic fertilizers were computed at Tier 1 level, using FAOSTAT fertilizer consumption statistics by country. This was the only category where, following IPCC guidelines, a single emission coefficient was used for all regions to estimate direct N_2O emissions. Indirect emissions due to volatilization and leaching were also included in our estimates. Emissions from synthetic fertilizers had the largest absolute growth rates in agriculture. They grew on average 19% yr^{-1} during the reference period 1961-2010, specifically more than ten times, i.e., from 0.07 to 0.68 $GtCO_2eq\ yr^{-1}$. Growth slowed down in recent decades, to about 2% yr^{-1}. At the current pace, emissions from synthetic fertilizers will overtake those from manure N left on pasture within a decade—becoming the second largest agriculture emission category after enteric fermentation. In 2010, 70% of emissions from synthetic fertilizer were from developing countries. During the period 2000-2010, Asia was by far the largest emitter (63%), followed by the Americas (20%) and Europe (13%). Emissions growth rates over the same period were robust in Asia (5.3% yr^{-1}) and Europe (1.7% yr^{-1}), but negative in Africa (-3.3% yr^{-1}). Emissions and application of synthetic fertilizers had a year-on-year drop in 2008 in some regions, specifically -4.4% (Europe) and -9.8% (Americas)—although not statistically significant, the drop coincides with increased fertilizer costs that year.

Rice

Emissions from rice cultivation were computed at Tier 1 level, using FAOSTAT statistics of harvested rice area and a regional-level distribution of rice management types and emission factors from the 1996 IPCC guidelines. Globally, during the reference period 1961-2010 GHG emissions grew slowly, from 0.37 to 0.49 $GtCO_2eq\ yr^{-1}$, with average annual growth rates of 0.7% yr^{-1}. It should be noted that our emissions estimates are in line with recent assessments (*Yan et al.*, 2009), which have revised down previously published data and databases (i.e., EDGAR, EPA).

Global emission growth slowed down in recent decades and likely reached a plateau in recent years—and even decreased on a year-on-year basis in several years during the period 2000-2010. Emissions from rice were dominated by developing countries, which contributed over 94% of emissions during 2000-2010. Asia was the largest contributor (89%), followed by the Americas (5%), Africa (4%) and Europe (1%). Emissions growth rates were nonetheless largest in Africa (1.8% yr^{-1}), followed by Europe (1.4%). Growth rates in Asia and the Americas were lower (0.2% yr^{-1}).

Global and Regional Trends in Emissions from Deforestation

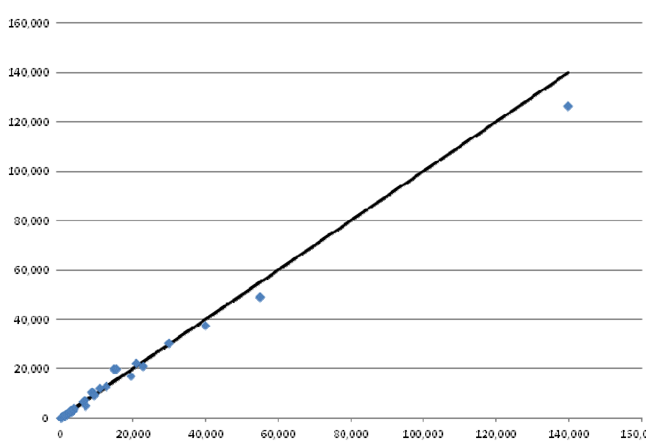
GHG emissions from net forest conversion by country were computed at Tier 1, by using net forest land-use change—afforestation minus deforestation—by country, reported FAOSTAT from FRA data. This area was multiplied by country-level averages of C content in living forest biomass. The latter data is a Tier 2-3 assessment of biomass carbon stocks, provided by member countries to *FAO* (2010). Emissions from net source countries were then aggregated globally, to estimate a carbon loss from deforestation, while those from net sink countries were aggregated separately to estimate a carbon sink from afforestation. Losses and gains thus computed were considered to be instantaneous at the time of the reported land use changes, as per IPCC guidelines (*IPCC*, 2006). It should be noted that carbon losses from deforestation as well as gains from afforestation are underestimated by using in FAOSTAT and FRA data relative to net area change. Indeed, any afforestation activity in a net source country will imply greater deforestation rates than the net values derived herein; likewise, a net sink country may still have undergone some deforestation, resulting in actual larger afforestation rates than the net values imply. Using data from 2005 (*FAO*, 2010) that had a more detailed breakdown of deforestation and afforestation activities within most countries, we estimated that actual deforestation rates in 2005 were about 20% larger than those estimated by using the net area changes used herein. The net global atmospheric signal derived by summing sinks and sources is, however, accurate—indeed such estimates are used routinely for global carbon balance assessments (e.g., *Houghton et al.*, 2012).

Global carbon emissions from net deforestation during the period 2005-2010 were estimated to be 3.4 $GtCO_2eq\ yr^{-1}$, in line with recent literature (see, e.g., *Friedlingstein et al.*, 2011). These emissions have decreased steadily since 1990, with average growth rates of -1.1% yr^{-1}, and including a pronounced slow-down since the year 2000 (-2.2% yr^{-1}). During the period 2000-2010, carbon emissions from deforestation were largest in the Americas (60%), followed by Africa (32%), Oceania (4%) and Asia (3%). All regions exhibited a declining emission growth rate, with the largest in Asia (-18% yr^{-1}). The Americas (-2.9% yr^{-1}) and Africa (0.2% yr^{-1}) showed smaller decreases, while emissions from deforestation grew only in Oceania, and significantly so (+45% yr^{-1}), largely due to the contribution of Papua New Guinea. As shown in Fig. 2, over the period 2000-2010, Brazil, Indonesia, Nigeria and the Democratic Republic of Congo had the largest net emission rates; China, the US, Viet Nam and India had the largest absolute net sequestration rates.

3.4 Methodological issues

A number of key methodological issues need to be addressed in developing a GHG central database and assessment at FAO. Because such new methodological and data tools aim at supporting IPCC and UNFCCC/SBSTA processes, IPCC methodologies (Tier 1-3) are used were possible, to be supplemented with additional FAO-developed methodologies and protocols. As discussed above, the FAOSTAT GHG database is based on Tier 1 IPCC guidelines and methodologies. First, there is a need for a coherent database where each country can be meaningfully compared within regions and with respect to global trends—current UNFCCC data are based on a range of country-level choices for emission factors and methodological approaches. Secondly, it is up to member countries to decide which methodologies they want to use in order to compute and report their GHG emissions to the climate convention.

Figure 4. Example of GHG data comparison against a benchmark. Data on annual GHG emissions from enteric fermentation from livestock, as reported by member countries to UNFCCC and as estimated by the FAOSTAT GHG database.



As a result, there are four dimensions of use by countries of the FAOSTAT GHG database: i) As a reporting tool for regular updates by FAO on the status of global and regional GHG emissions; to be used for both science and policy processes; ii) As a learning tool as well as a mean to fill missing data by member countries with low capacity, as a bridge until further data collection, analysis and management capacity is built; iii) As a benchmark for all reporting member countries, to be used as a standard against which national-level estimates can be compared and justified (Fig. 4). Currently the same exercise is undertaken in the energy sectors, using data from the IEA; iv) As a provider of indicators, for instance GHG emissions per unit commodity, to be used for national level analysis and international support to the climate policy debate.

Furthermore, frequency and spatial scale of measurements needs to be determined in order to provide wide application by end user countries (e.g., resolving spatial variability issues through, pilot sampling, remote sensing and stratification). Determination of the choice of unit will be important. For example, emissions per unit of a single commodity will be different from emissions per unit of nutritive value (e.g. protein or calories) which might also be context-specific.

Geo-referenced data on cropping systems and the application of remote sensing will be needed for the detection and classification of land-use changes. For emissions from land-use change, an agreement will be needed upon how to handle emissions timing. Timing of emissions must be considered. Indeed, different times of actual physical emissions are typically applied in order to count relatively immediate land-use change emissions over time. To date, this aspect of timing is handled in one of three ways: counting all emissions instantaneously, using an amortization period, and using some form of discount rate.

On needed guidance, issues relate to guidance on the scale of application, which would vary with the type of emissions and activities or products considered; guidance on the accounting of co-products from agricultural production; guidance on the level of uncertainty acceptable for different mitigation uses (e.g. offsets, Nationally Appropriate Mitigation Actions - NAMAs) and for assessing this uncertainty; and guidance on emission segregation (from unregulated emissions) that is otherwise subject to limitations. Finally, analysis calculating mitigation benefits should take account of the robustness of the practice in achieving the projected reduction, i.e. how dependent the reductions are on the details of the implementation. More robust practices should receive higher awards/incentives.

5. Conclusions

FAOSTAT current efforts in the area of agri-environmental indicators have led to the compilation of new data relevant to the increasing interest of its member countries to monitor, analyse and report critical information for analysis and policy making. Within this context, the ongoing efforts are fully consistent with and can significantly support the Global Strategy and SEEA development goals. In particular, FAOSTAT is expanded to include an assessment of GHG emissions and mitigation potentials from agriculture, in close collaboration with IPCC guidelines and UNFCCC requirements. A work programme was developed with a focus on improvement of the data collection process, country capacity building, development of country case studies, the processing and analysis required in developing a global assessment. Such activities support the creation of detailed technical guidance for potential appropriate national mitigation actions (NAMA) in developing countries and especially LDCs. The development of a data warehouse for FAOSTAT and other FAO databases is underway and will lead to easier integration and use of the agri-environmental data held in FAO.

An international framework for the integration and expansion of existing assessments based on IPCC principles and methods for AFOLU, is is open to partnership with interested stakeholders, including technical experts, universities, government institutions and the private sector, focusing on:

- Detail a work programme on data collection process, country capacity building, development of country case studies towards improving national, regional and global assessments;
- Survey a sample of countries for barriers and limitations to adopting or developing GHG emission databases and use this information to help devise a strategy to overcome the issues;
- A set of country case studies for capacity building to address both technical and institutional gaps;
- Peer-review of FAOSTAT databases to improve agri-environmental and GHG data services.

With respect to the GHG database, to be released by the end of 2012, applications by member countries can be structured along four dimensions:

As a result, there are four dimensions of use by countries of the FAOSTAT GHG database:

i) Global Analysis: for regular updates by FAO on the status of global and regional GHG emissions; to be used for both science and policy processes;
ii) Capacity Building: learning tool for member countries with low capacity, as a bridge until further data collection, analysis and management capacity is built;
iii) Benchmarking: to be used as a standard against which national-level estimates can be compared and justified internationally.
iv) Indicators: to be used for national level analysis and international support to the climate policy debate.

These four dimensions provide guidelines for capacity building to improve national data and institutional coordination needed for robust and internationally accepted national, regional and global GHG emissions estimates, with a view to support a more significant role of agriculture in post-2012 UNFCCC climate agreements and related mechanisms.

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