Abbreviations

ABP	animal products and by-products
AEZ	agro-ecological zone
BFM	bone-free meat
Bo	manure maximum CH_4 producing capacity
CF	carbon footprint
CGIAR	Consortium of International Agricultural Research Centers
CH_4	methane
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
CW	carcass weight
DM	dry matter
DMI	dry matter intake
DOM	dead organic matter
FCR	feed conversion ratio
EF	emission factor
EI	emission intensity
FPCM	fat and protein corrected milk
GHG	greenhouse gas
GLEAM	Global Livestock Environmental Assessment Model
GIS	Geographical Information System
GPP	gross primary production
GWP	global warming potential
HCFC	hydrochlorofluoro carbon
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg CO_2-eq	kilograms of CO_2 equivalent
LAC	Latin America and the Caribbean
LCA	life cycle assessment
LCI	life cycle inventory
LPS	livestock production system
LUC	land-use change
LULUCF	land use, land-use change and forestry
LW	live weight
MC	Monte Carlo Simulation
MCF	methane conversion factor
MMS	manure management system
N	nitrogen
NENA	Near East & North Africa
NH_3	ammonia
NIR	national inventory report
NO_X	nitrogen oxide air pollutants NO and NO_2 (nitric oxide and nitrogen dioxide)

N₂O	nitrous oxide
OECD	Organisation for Economic Cooperation and Development
PDF	probability distribution frequency
RCC	Rank Correlation Coefficient
SD	standard deviation
SSA	Sub-Saharan Africa
SOC	soil organic carbon
SPAM	Spatial Production Allocation Model
SRM	specified risk material
t CO₂-eq	tonnes of CO_2 equivalent
UNFCCC	United Nations Framework Convention for Climate Change
USDA	United States Department of Agriculture

Definitions of commonly-used terms

Anaerobic In the absence of oxygen, i.e. conditions conducive to the conversion of organic carbon into methane (CH_4) rather than carbon dioxide (CO_2).

Breeding overhead Animals that are kept to maintain the herd/flock size, rather than to produce food.

By-product Material produced during the processing including slaughtering of a crop or livestock product that is not the primary objective of production (e.g. meals and brans, offal or skins).

Carbon footprint The total amount of GHG emissions associated with a product along its supply-chain, and sometimes includes emissions from consumption, end-of-life recovery and disposal. Usually expressed in kg or t of carbon dioxide equivalent (CO_2-eq).

CO_2-equivalent emission The amount of CO_2 emissions that would cause the same time-integrated irradiative forcing, over a given time horizon, as an emitted amount of a mixture of GHGs. It is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon. The CO_2 equivalent emission is a standard metric for comparing emissions of different GHGs (IPCC, 4 AR 2007).

Coefficient of variation The standard deviation expressed as a percentage of the mean.

Cohort Class of animals within a herd defined by their age and sex (e.g. adult females, replacement females, males for fattening, etc.).

Co-product Material generated by a production activity that generates more than one output (e.g. meat, eggs and manure are co-products of chicken production).

Crop residue Materials left in an agricultural field after the crop has been harvested (e.g. straw or stover).

Dairy herd	For the purposes of this assessment, includes milking animals, replacement stock and surplus calves that are fattened for meat production.
Direct energy	Energy used on-farm for livestock production, e.g. for lighting, heating and cooling.
Embedded energy	Energy or emissions arising during the manufacture of farm inputs, such as fertiliser or steel.
Emission factor	Factor that defines that rate at which a greenhouse gas is emitted, e.g. kg CH_4 per animal per year or kg N_2O-N/kg manure N.
Emissions intensity	Mass of emissions per unit of product, e.g. kg CO_2/kg of meat/milk.
Fat and protein corrected milk (FPCM)	Milk corrected for its fat and protein content to a standard of 4.0 percent fat and 3.3 percent protein. This is a standard used for comparing milk with different fat and protein contents. It is a means of evaluating milk production of different dairy animals and breeds on a common basis.
Feed conversion ratio	Measure of the efficiency with which an animal converts feed into tissue, usually expressed in terms of kg of feed per kg of output (e.g. CW, milk or protein).
Feed material	Individual feed type (e.g. maize grain or wheat straw).
Fieldwork	General term for the field operations undertaken during crop cultivation, e.g. ploughing, drilling, spreading, etc.
Geographical Information System	A computerized system organizing data sets through the geographical referencing of all data included in its collections.
Globalwarming potential	Defined by the Intergovernmental Panel on Climate Change (IPCC) as an indicator that reflects the relative effect of a GHG in terms of climate change considering a fixed time period, such as 100 years, compared with the same mass of carbon dioxide.
Grassland-based livestock systems	Livestock production systems in which more than 10 percent of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than ten livestock units per hectare of agricultural land (FAO, 1996).

Manure N	Nitrogen in manure.
Methane conversion factor	The percentage of the manure's maximum methane producing capacity (Bo) that is achieved during manure management
Mixed farming systems	Livestock production systems in which more than 10 percent of the dry matter fed to livestock comes from crop by-products and/or stubble or more than 10 percent of the value of production comes from non-livestock farming activities (FAO, 1996).
Monte Carlo analysis	Method that uses repeated random sampling for estimating uncertainty in results.
Pixel	The smallest unit of information in GIS raster data, usually square in shape. In GIS dataset, each pixel represents a portion of the earth, and usually has an attribute value associated with it, such as soil type or vegetation class. Pixel is often used synonymously with cell.
Ration	The combination of feed materials constituting the animal's diet.
Synthetic N	Nitrogen in the form of manufactured fertilisers, such as ammonium nitrate.
Tier levels	Defined in IPCC (2006), these correspond to a progression from the use of simple equations with default data (Tier 1 emission factors), to country-specific data in more complex national systems (Tier 2 & 3 emission factors). Tiers implicitly progress from least to greatest levels of certainty as a function of methodological complexity, regional specificity of model parameters, spatial resolution and the availability of activity data.

Executive summary

BACKGROUND AND PURPOSE

In decades to come, the global demand for livestock products will continue to increase driven by growing populations, incomes and urbanization. As a consequence the sector needs to produce more but in a context of increasing natural resource scarcity and challenges posed by climate change.

In 2010, the ruminant sector contributed about 29 percent to global meat production (equivalent to 81 million tonnes) of which 79 percent is from the cattle sector and the remaining from buffalo and small ruminants. Global milk production in 2010 was 717 million tonnes with milk production from the cattle sector contributing the bulk, about 83 percent of global production.

While ruminants play an important role in providing high quality protein essential for human diets, they are an important source of greenhouse gas (GHG) emissions. The demand for bovine meat, mutton and milk is forecasted to grow at a rate of 1.2 percent, 1.5 percent and 1.1 percent, respectively, during the period 2006-2050. To avoid significant increases in total GHG emissions from the sector, a reduction of the intensity of emissions is required.

This report presents a life cycle analysis of the GHG emissions arising from ruminant supply chains around the year 2005. This first comprehensive and disaggregated global assessment of emissions enables the understanding of emission pathways and hotspots. This is a fundamental and initial step to identify mitigation strategies and inform public debate.

Two similar reports on the emissions from pig and chicken supply chains and on the emissions from the dairy sector are also available. An overall report providing an overview of results and exploring mitigation potential and options is also available.[1]

METHODOLOGY

This assessment is based on a life cycle assessment (LCA) and includes all main sources of emissions along the supply chain starting from land use and the production of feed, through emissions from animal production to emissions related to processing and transportation of products to the retail distribution point.

GHG emissions arising from land-use change (LUC) associated with livestock production were also assessed. Land-use change emissions considered include the transformation of forest to cropland and of forest to pasture in Latin America and the Caribbean. Given the year of reference (2005), latest trends could not be fully reflected (e.g. reduction of deforestation rates in LUC). A sensitivity analysis was conducted, showing that the period of the analysis has an important influence on results.

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[1] FAO. 2010. Greenhouse gas emissions from the dairy sector – A life cycle assessment. FAO, Rome.
FAO. 2013a. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. FAO, Rome.
FAO. 2013b. Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment. FAO, Rome.

Due to the lack of globally validated model and databases, sequestration and losses of soil C arising from pasture management could not be included in the assessment but can be significant. The effect of this was tested in the case of Western Europe; carbon sequestration could mitigate about 5 percent of total ruminant emissions in the region, but with a high degree of uncertainty.

This analysis covers emissions from the three major GHGs in agriculture, namely methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), omitting gases of minor importance.

The analysis was undertaken using the Global Livestock Environmental Assessment Model (GLEAM). This model quantifies GHG emissions arising from production of the main livestock commodities: meat and milk from cattle, sheep, goats and buffalo; meat from pigs; and meat and eggs from chickens.

The model calculates total emissions and (commodity) production for a given farming system within a defined area. The emissions per unit of product can be calculated for combinations of different commodities/farming systems/locations at different spatial scales.

In a complex analysis such as this, results are not definitive, but rather the best assessment that could be made and subject to improvement in subsequent revisions. Methodological developments are being developed within the context of the LEAP Partnership (Livestock Environmental Assessment and Performance),[2] to harmonize metrics and approaches used in the assessment of environmental performance of livestock supply chains, including future updates of this report.

KEY FINDINGS
Overall sectoral contribution to global GHG emissions
Globally, ruminant supply chains are estimated to produce 5.7 gigatonnes CO_2-eq *per annum* representing about 80 percent of the livestock sector emissions. Emissions from beef and milk production represent respectively 35 and 30 percent of the livestock sector emissions (equivalent to 4.6 gigatonnes CO_2-eq). Buffalos and small ruminants supply chains have a much lower contribution, representing respectively 8.7 percent and 6.7 percent of sector emissions.

Main emission sources
The largest source of GHG emissions in ruminant production is methane (CH_4) from enteric fermentation, which accounts for about 47 percent of the sector's emissions and more than 90 percent of the total CH_4 emissions. Nitrous oxide (N_2O) emissions originating mainly from feed production and N deposited during grazing represent 24 percent of the sector's GHG emissions.

Emissions from land-use change associated with the expansion of grassland into forest account for 14.8 percent of total emissions related to beef production.

While LUC contributes a significant amount to total emissions; and particularly so in certain regions, these estimates vary greatly depending on the assumptions made, data and approach applied.

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[2] http://www.fao.org/ag/againfo/livestock-benchmarking/en/.

Emission intensities (emission of GHG per unit of product) per commodity
Average emission intensity for products from ruminants were estimated at 2.8, 3.4 and 6.5 kg CO_2-eq/kg fat and protein corrected milk (FPCM) for cow milk, buffalo and small ruminant milk, respectively, and 46.2, 53.4, and 23.8 kg CO_2-eq/kg carcass weight (CW) for beef, buffalo and small ruminant meat, respectively.

EMISSION INTENSITIES PER PRODUCTION SYSTEMS AND REGIONS
There are variations in emission intensities across regions and production systems for each commodity. These variations are largely driven by differences in production goals (specialized versus non-specialized production) and management practices, including animal husbandry methods, animal health and genetics which influence levels of productivity.

In addition, there is a wide divergence in emission intensity for different commodities produced within the same region under comparable conditions (production systems and climatic zones) pointing to the existence of a considerable emission intensity gap (Section 4.4).

Variation by production systems
Globally, mixed systems provide the bulk of the meat and milk output: about 79 percent of the beef, 85 percent of cow's milk and 70 and 68 percent of small ruminant milk and meat is produced in this system. In addition, mixed systems also supply about 97 and 96 percent of buffaloes' milk and meat, respectively.

On average, mixed systems have slightly lower emission intensities than grassland-based systems. This difference is explained by several factors such as reproductive efficiency (higher fertility rates, lower age at calving,) animal health (lower mortality rates), management (higher slaughter weights, reduced time to slaughter), and better feed quality in mixed farming systems. All these factors combine to result in higher productivity and lower emission intensity.

Variation by region
World regions show highly diverse emission intensities which are to large extent explained by their contribution to production, their production systems and management practices.

Cattle
Regional emission intensity of milk ranges from 1.6 kg CO_2-eq/kg FPCM to 9.0 kg CO_2-eq/kg FPCM. Generally, milk production in low productive systems has higher emission intensities than in high production systems of most affluent counties where better animal feeding and nutrition results in lower enteric and manure emissions and emission intensity at animal level. Improved genetics and animal health care and animal husbandry combine with better feeding to reduce the breeding overhead (i.e. animals kept to maintain the herd) thus further reducing emission intensity at herd level. In North America, manure management emissions are relatively high due to the use of liquid manure management systems that produce greater quantities of methane emissions.

Emission intensity of beef at regional level show a great deal of diversity; ranging from 14 kg CO_2-eq/kg CW in Eastern Europe and the Russian Federation to 76 kg CO_2-eq/kg CW in South Asia. Beef production has the highest emission intensi-

ties in South Asia, sub-Saharan Africa, Latin America and the Caribbean, and East and Southeast Asia. The quality and type of feed, low reproduction efficiency, poor herd management practices, genetics and animal health (high mortality) explain the higher emission intensities in these regions. In addition, in Latin America and the Caribbean, almost one third of the emissions from beef production are related to pasture expansion into forested areas. This figure is however associated with a high level of uncertainty as a result of methodological uncertainty and data gaps.

Regions with the lowest emission intensity such as Europe, North America and Oceania are not necessarily characterized by similar production systems. For example, in Europe about 80 percent of the beef is produced from dairy surplus calves and culled cows which explains the relatively low emission intensity of beef. In North America and Oceania, production is generally characterized by a high level of specialization and higher productivity, which results in lower emission intensities. However, in these two regions, beef cattle may be reared either intensively or extensively (on grain or grass).

Buffalos

Global buffalo milk and meat production is concentrated in three major world regions: South Asia, Near East & North Africa and East & Southeast Asia. South Asia alone produces as much as 90 percent and 70 percent of the global buffalo milk and meat, respectively. Milk produced in South Asia has lower emission intensity, explained by high milk yields compared to Near East & North Africa and East & Southeast Asia. Emission intensity of buffalo meat production is particularly high in East & Southeast Asia as productivity of the animals is low due to poor feed resources (largely based on low quality feed resources such as crop residues and pasture) and low reproductive efficiency. With the exception of a few countries in the Mediterranean region, buffalo production in industrialized world regions plays a very minor role.

Small ruminants

With the exception of small ruminant milk production in Western Europe and lamb and mutton production in Oceania and Western Europe, meat and milk from small ruminants is generally more important in developing world regions. Emission intensity for small ruminant milk is however highest in developing regions such as NENA and East & Southeast Asia, SSA and South Asia due to poorer production conditions in which animals are for the most part reared for subsistence purposes. In contrast, in industrialized countries where small ruminant milk production is important, emission intensity is low due to the specialization of production.

The contribution to global small ruminant meat production is characterized by a dichotomy between regions; global lamb and mutton production is largely concentrated in Western Europe and Oceania while production of meat from goats takes place in developing regions. Emission intensity for small ruminant meat is lowest in Oceania and Western Europe and highest in developing regions.

This difference in emission intensity of small ruminant meat and milk is due to variations in reproductive efficiency (resulting in a smaller "breeding overhead"), feed quality, and management practices that are generally poorer in developing regions.

FACTORS DRIVING EMISSION INTENSITY LEVELS

Differences in emission intensities are driven by a combination of factors.

- At animal level emission intensity is influenced by: (i) digestibility, quality and composition of the feed ration which influence the level of enteric methane emissions and manure emissions (lower release of nitrogen and volatile solids) per unit of product produced (milk or weight gain); and (ii) improved genetics and animal health contribute to better conversion of feed into animal products further reducing emission intensity at animal level.
- At animal level, emission intensity is influenced by feed quality combined with genetics, animal health, reproduction strategies (replacement, age at first calving) reducing the relative number of unproductive animals in the herd and thus emissions per unit of product generated at herd level.
- Land-use change, i.e. pasture and feed crop expansion, is a major driver of emissions. Feed originating from areas where LUC takes place has higher emission intensities.
- Manure management practices influence the release of methane and nitrous oxide.

CONCLUSIONS

The range of emission intensity within supply chains suggests that there is room for improvement. The areas with mitigation potential are the following:

- Improving feeding practices and digestibility of diets;
- Improving yields through genetics, feeding practices and animal health, and overall management;
- Reducing land-use change arising from feed crop cultivation and pasture expansion;
- Improving manure management – reducing the use of uncovered liquid manure management systems (MMSs), particularly in dairy systems;
- Improving the efficiency of feed crop production, particularly improving fertilization management.

This report focuses on one measure of environmental performance: kg CO_2-eq/ kg commodity. When evaluating GHG mitigation measures, attention should also be paid to their potential impacts on other environmental dimensions, for example on water quality, as well as on broader development objectives, such as food security and poverty reduction.