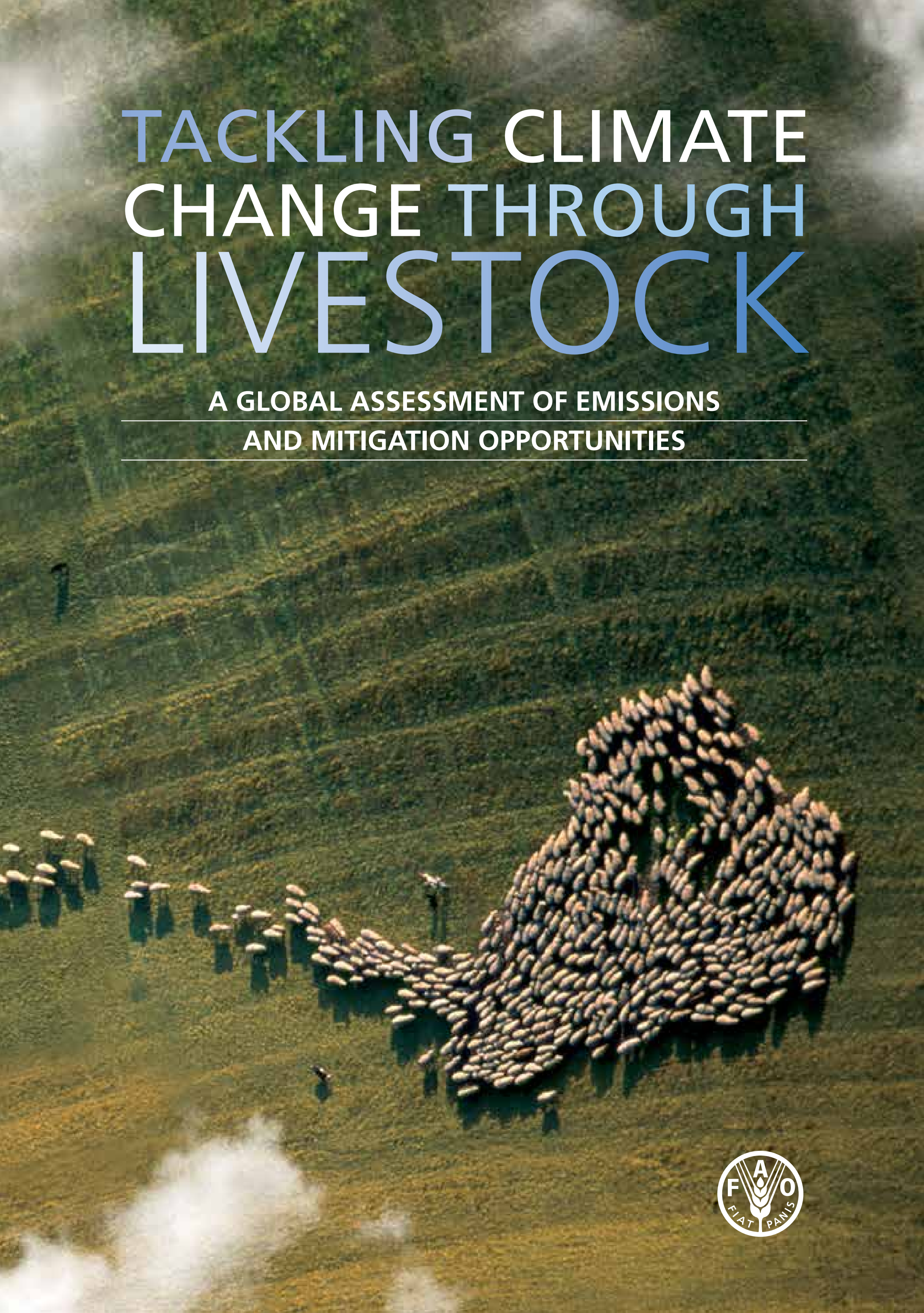

TACKLING CLIMATE CHANGE THROUGH LIVESTOCK

A GLOBAL ASSESSMENT OF EMISSIONS AND MITIGATION OPPORTUNITIES

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Foreword

It is easy to draw a dramatic picture of today's world. Climate change, the most serious environmental challenge humanity has to face, is threatening the well-being of the next generation. Globalization has led to rapid economic, social and technological changes that have left too many behind. Hunger is still a persistent problem, affecting over 900 million human beings worldwide. Faced with these issues, we sometimes feel overwhelmed by their magnitude and powerless.

But we need not despair. Difficult problems can be tackled for the benefit of many if we apply the right policies that support the required innovation and investment.

We have known for several years that livestock supply chains are an important contributor to climate change. This new report shows that the potential to significantly reduce emissions exists and is within reach. Options are available for all species, systems and regions. But we need political will and better policies.

The report provides much-needed data that will allow us to move forward. It presents an evidence-based picture of emissions with data broken down by species, agro-ecological zones, regions and production systems. The breadth of information provided by this report and the two complementary technical reports[1] reflect the vast diversity of the livestock sector.

A detailed understanding of the magnitude, sources and pathways of emissions is essential to inform policy dialogue and avoid oversimplifications. It will help us to make more informed choices about livestock policies in support of sustainable food production, economic growth and poverty alleviation.

This report identifies ways of reducing emissions by assessing the mitigation potential of sets of technologies. Such analysis provides guidance for local and system-specific solutions, as sector actors seek to improve sustainability and viability, but also for more targeted pro-poor livestock development.

The work of the Food and Agricultural Organization of the United Nations (FAO) in assessing the environmental impact of livestock production (of which this report forms part) has triggered the interest and support of multiple partners engaging with FAO to improve data and analysis. The Livestock Environmental Assessment and Performance (LEAP) Partnership focuses on the development of broadly recognized sector-specific guidelines and metrics for assessing and monitoring the environmental performance of the sector.

Increasingly, sector actors realize that the growing scarcity of natural resources may well shape the sector's future and they have started to address its environmental impact. Reflecting these concerns, a wide range of partners have engaged in a global policy dialogue with FAO. The Global Agenda of Action in support of Sustainable Livestock Sector Development aims to catalyse and guide stakeholder action towards the improvement of practices for a more efficient use of natural resources.

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[1] FAO, 2013a. *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment.*
FAO, 2013b. *Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment.*

Better knowledge and growing willingness to act create a momentum to tackle climate change with livestock. We should not miss it. As the effect of climate has started to be felt in everyone's life, collective action is now urgently needed.

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This report presents the results from a global assessment of greenhouse gas (GHG) emissions along livestock supply chains. The analysis was conducted at FAO's Animal Production and Health Division (AGA), headed by Berhe Tekola, and co-financed by the Mitigation of Climate Change in Agriculture (MICCA) programme.

The report was written by the following FAO staff members: Pierre Gerber, Henning Steinfeld, Benjamin Henderson, Anne Mottet, Carolyn Opio, Jeroen Dijkman, Alessandra Falcucci and Giuseppe Tempio.

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Overview

Climate change is transforming the planet's ecosystems and threatening the well-being of current and future generations. To "hold the increase in global temperature below 2 degrees Celsius" and avoid "dangerous" climate change,[2] deep cuts in global emissions are urgently required.

The global livestock sector contributes a significant share to anthropogenic GHG emissions, but it can also deliver a significant share of the necessary mitigation effort.

Concerted and collective action from all sector stakeholders is urgently required to ensure that existing and promising mitigation strategies are implemented. The need to reduce the sector's emissions and its environmental footprint has indeed become ever more pressing in view of its continuing expansion to ensure food security and feed a growing, richer and more urbanized world population.

LIVESTOCK: A SIGNIFICANT CONTRIBUTOR TO CLIMATE CHANGE

With emissions estimated at 7.1 gigatonnes CO_2-eq per annum, representing 14.5 percent of human-induced GHG emissions, the livestock sector plays an important role in climate change.

Beef and cattle milk production account for the majority of emissions, respectively contributing 41 and 20 percent of the sector's emissions. While pig meat and poultry meat and eggs contribute respectively 9 percent and 8 percent to the sector's emissions. The strong projected growth of this production will result in higher emission shares and volumes over time.

Feed production and processing, and enteric fermentation from ruminants are the two main sources of emissions, representing 45 and 39 percent of sector emissions, respectively. Manure storage and processing represent 10 percent. The remainder is attributable to the processing and transportation of animal products.

Included in feed production, the expansion of pasture and feed crops into forests accounts for about 9 percent of the sector's emissions.

Cutting across categories, the consumption of fossil fuel along the sector supply chains accounts for about 20 percent of sector emissions.

IMPORTANT REDUCTIONS IN EMISSIONS WITHIN REACH

Technologies and practices that help reduce emissions exist but are not widely used. Their adoption and use by the bulk of the world's producers can result in significant reductions in emissions.

Emission intensities (emissions per unit of animal product) vary greatly between production units, even within similar production systems. Different farming practices and supply chain management explain this variability. Within the gap between the produc-

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[2] Copenhagen Accord, 2009. COP 15.

tion units with the lowest emission intensities and those with the highest emission intensities, lies an important potential for mitigation.

A 30 percent reduction of GHG emissions would be possible, for example, if producers in a given system, region and climate adopted the technologies and practice currently used by the 10 percent of producers with the lowest emission intensity.

EFFICIENT PRACTICES KEY TO REDUCING EMISSIONS

There is a direct link between GHG emission intensities and the efficiency with which producers use natural resources. For livestock production systems, nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) emissions, the three main GHG emitted by the sector, are losses of nitrogen (N), energy and organic matter that undermine efficiency and productivity.

Possible interventions to reduce emissions are thus, to a large extent, based on technologies and practices that improve production efficiency at animal and herd levels. They include the use of better quality feed and feed balancing to lower enteric and manure emissions. Improved breeding and animal health help to shrink the herd overhead (i.e. unproductive part of the herd) and related emissions.

Manure management practices that ensure the recovery and recycling of nutrients and energy contained in manure and improvements in energy use efficiency along supply chains can further contribute to mitigation. Sourcing low emission intensity inputs (feed and energy in particular) is a further option.

ADDITIONAL PRACTICES WITH PROMISING MITIGATION POTENTIAL

Grassland carbon sequestration could significantly offset emissions, with global estimates of about 0.6 gigatonnes CO_2-eq per year. However, affordable methods for quantifying sequestration, as well as a better understanding of institutional needs and economic viability of this option, are required before it can be implemented at scale.

A range of promising technologies such as feeding additives, vaccines and genetic selection methods have a strong potential to reduce emissions but require further development and/or longer time frames to be viable mitigation options.

MITIGATION INTERVENTIONS TO CONTRIBUTE TO DEVELOPMENT

Most mitigation interventions can provide both environmental and economic benefits. Practices and technologies that reduce emissions can often simultaneously increase productivity, thereby contributing to food security and economic development.

MITIGATION POTENTIAL ACROSS THE BOARD

Substantial emission reductions can be achieved across all species, systems and regions. Mitigation solutions will vary across the sector as emission sources, intensities and levels vary amongst species, production systems and regions, but the mitigation potential can be achieved within existing systems; this means that the potential can be achieved as a result of improving practices rather than changing production systems (i.e. shifting from grazing to mixed or from backyard to industrial).

The major mitigation potential lies in ruminant systems operating at low productivity (e.g. in South Asia, Latin America and the Caribbean, and Africa). Part of the mitigation potential can be achieved through practices related to better feeding, animal health and herd management.

In the most affluent regions, where emission intensities of ruminant production are relatively low but the volume of production and emissions remain high, small reductions in emission intensity can nonetheless result in large emission reductions (e.g. dairy production in Europe and North America). In these areas where animal and herd efficiency is already high, mitigation can be achieved by improvements in other farm operations such as manure management, energy use and the sourcing of feed with lower emission intensity.

Sizeable reductions could also be achieved in intermediate pork and poultry production systems, in particular, in East and Southeast Asia which rely on purchased, high emission intensity inputs, but do not operate at high efficiency levels.

ENABLING ENVIRONMENTS CRUCIAL FOR UNLEASHING MITIGATION POTENTIAL

Supportive policies, adequate institutional and incentive frameworks and more proactive governance are needed to fulfil the sector's mitigation potential.

Awareness-raising and extension are important first steps towards the adoption of better technologies and practices. These require investments in communication activities, demonstration farms, farmer field schools, farmer networks and training programmes. Sector organizations can play an important role in raising awareness among producers and disseminating best practices and mitigation success stories.

While many of the mitigation practices are likely to be profitable in the mid-term, public policies should ensure that farmers can face initial investment and possible risks. This is particularly important in least affluent countries, where limited access to credit and risk adverse strategies will prevent the uptake of novel options requiring upfront investment. The provision of microfinance schemes can be effective to support the adoption of new technologies and practices by small-scale farmers. Where the adoption of technologies and practices are costly for farmers in the short or medium term, but provide large public mitigation benefits, abatement subsidies should be envisaged.

Public and private sector policies also have a crucial role to play in supporting research and development to improve the applicability and affordability of existing technologies and practices, and to provide new solutions for mitigation. Significant additional research is also needed to assess the costs and benefits of mitigation options in practice.

Efficiency-based mitigation strategies will not always result in a reduction of emissions, especially where production grows rapidly. While keeping rural development and food security issues in consideration, complementary measures may be needed to ensure that overall emissions are curbed. Further, safeguards should be in place to avoid the potential negative side-effects of efficiency gains, such as animal diseases, poor welfare, and soil and water pollution.

International efforts should be pursued to ensure that mitigation commitments, both within and outside the United Nations Framework Convention on Climate Change (UNFCCC), are strengthened to provide stronger incentives to mitigate livestock sector emissions and ensure that efforts are balanced through the different sectors of the economy.

In least affluent countries where the mitigation potential is important, it is crucial to set up sector development strategies that serve both mitigation and development objectives. Such strategies may well condition the wider adoption of mitigation practices.

NEED FOR COLLECTIVE, CONCERTED AND GLOBAL ACTION

Recent years have seen interesting and promising initiatives by both the public and private sectors to address sustainability issues. Complementary multistakeholder action is required to design and implement cost-effective and equitable mitigation strategies, and to set up the necessary supporting policy and institutional frameworks.

It is only by involving all sector stakeholders (private and public sector, civil society, research and academia, and international organizations) that solutions can be developed that address the sector's diversity and complexity. Climate change is a global issue and livestock supply chains are increasingly internationally connected. To be effective and fair, mitigation actions also need to be global.

Abbreviations and acronyms

AEZ	Agro-ecological zone
ABC	Low Carbon Agriculture programme, of the Government of Brazil
AGA	Animal Production and Health Division (FAO)
AGGP	Agricultural Greenhouse Gases Program
APS	Alternative policy scenario
BAU	Business as usual
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CFI	Carbon Farming Initiative (Australia)
CGIAR	Consultative Group on International Agricultural Research
CW	Carcass weight
DE	Digestible energy
DM	Dry Matter
ETS	Emission Trading Scheme (European Union)
FCPF	Forest Carbon Partnership Facility
FIP	Forest Investment Program
FPCM	Fat and protein corrected milk
GAEZ	Global Agro-Ecological Zone
GHG	Greenhouse gas
GIS	Geographic Information System
GLEAM	Global Livestock Environmental Assessment Model
GMI	Global Methane Initiative
GRA	Global Research Alliance (on Agricultural Greenhouse Gases)
GWP	Global warming potential
HFCs	Hydrofluorocarbons
IDF	International Dairy Federation
IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and the Caribbean
LCA	Life cycle assessment
LEAP	Livestock Environmental Assessment and Performance Partnership
LUC	Land-use change
MICCA	Mitigation of Climate Change in Agriculture
NAMA	Nationally Appropriate Mitigation Action
NASA	National Aeronautics and Space Administration
NENA	Near East & North Africa
NZAGRC	New Zealand Agricultural Greenhouse Gas Research Centre

OECD	Organisation for Economic Co-operation and Development
OTC	Over-the-counter
REDD+	Reducing Emissions from Deforestation and Forest Degradation Programme
SAI	Sustainable Agriculture Initiative
SIK	Swedish Institute for Food and Biotechnology
SSA	Sub-Saharan Africa
TNC	The Nature Conservancy
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VCS	Verified Carbon Standard
VS	Volatile solids
WRI	World Resources Institute

Glossary

Age at first calving (farrowing)	The time spent between birth and first calving (farrowing); i.e. the age at which a heifer (gilt) becomes a cow (sow).
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).
Anaerobic digesters	Equipment where anaerobic digestion is operated; i.e. the process of degradation of organic materials by microorganisms in the absence of oxygen, producing CH_4, CO_2 and other gases as by-products.
Backyard production system	Production that is mainly subsistence-driven or for local markets, displaying animal performance lower than in commercial systems and mostly relying on swill and locally-sourced materials to feed animals (less than 20 percent of purchased concentrate).
Breeding overhead	Animals dedicated to reproduction, rather than to production; i.e. animals necessary to maintain herd/flock size.
Broiler	Chicken reared for meat.
By-product	Material produced during the processing (including slaughtering) of a livestock or crop product that is not the primary objective of the production activity (e.g. oil cakes, brans, offal or skins).
Carbon footprint	The total amount of GHG emissions associated with a product along its supply chain; usually expressed in kg or t of carbon dioxide equivalent (CO_2-eq) per unit of output.
CO_2-eq emission	The amount of CO_2 emissions that would cause the same time-integrated radiative 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, 2007).

Cohort	Class of animals within a herd/flock defined by their age, sex and function (e.g. adult females, replacement females, males for fattening).
Co-product	Output from a production activity that generates more than one output (e.g. milk, meat, manure and skins are among the co-products of dairy production). The term does not include services that may also be provided (e.g. draught power).
Crop residue	Plant materials left in an agricultural field after harvesting (e.g. straw or stover).
Dairy herd	For the purposes of this assessment, includes all animals in a milk-producing herd: milked animals, replacement stock and surplus calves that are fattened for meat production.
Direct energy	Energy used on-farm for livestock production activities (e.g. for lighting, heating, milking and cooling).
Emission intensity (Ei)	Emissions per unit of output, expressed in kg CO_2-eq per unit of output (e.g. kg CO_2-eq per kg of egg).
Fat and protein corrected milk (FPCM)	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. Cow's milk is corrected for its fat and protein content to a standard of 4 percent fat and 3.3 percent protein.
Feed balancing	The action of selecting and mixing feed materials (e.g. forages, concentrates, minerals, vitamins, etc.) that are free from deleterious components, to produce an animal diet that matches animal's nutrient requirements as per their physiological stage and production potential (FAO, 2013d).
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. live weight, eggs or protein).
Feed digestibility	Determines the relative amount of ingested feed that is actually absorbed by an animal and therefore the availability of feed energy or nutrients for growth, reproduction, etc.
Feed processing	Processes that alter the physical (and sometimes chemical) nature of feed commodities to optimize utilization by animals (e.g. through drying, grinding, cooking and pelleting).

Forage off-take rate	The proportion of above-ground grassland vegetation that is consumed by livestock (grazed or harvested).
Geographic Information System (GIS)	A computerized system organizing data sets through the geographical referencing of all data included in its collections.
Global warming potential (GWP)	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.
Grazing production 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 (ha) of agricultural land (Seré and Steinfeld, 1996).
Greenhouse gas	A greenhouse gas (GHG) is a gas that absorbs and emits radiation within the thermal infrared range; this process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the earth's atmosphere are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3).
Indirect (or embedded) energy	Energy or emissions arising during the manufacture of farm inputs such as fertilizer or steel.
Industrial production systems	Large-scale and market-oriented livestock production systems that rely on fully enclosed housing, high capital input requirements (including infrastructure, buildings and equipment) and purchased non-local feed or on-farm intensively-produced feed. Industrial systems have high overall herd performances.
Intermediate production systems	Market-oriented livestock production systems that rely on partially enclosed housing, a medium level of capital input requirements and locally-sourced feed materials for 30 to 50 percent of the ration. Intermediate systems have reduced levels of performances compared with industrial systems.
Layer	Chicken reared to produce eggs for human consumption.
Methane conversion factor	The percentage of manure's maximum CH_4-producing capacity that is actually achieved during manure management; i.e. part of organic matter actually converted into CH_4.

Mixed production 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 (Seré and Steinfeld, 1996).
Natural resource use efficiency	Measured by the ratio between the use of natural resources as input to the production activities and the output from production (e.g. kg of phosphorus used per unit of meat produced, or ha of land mobilized per unit of milk produced).
Productivity	Amount of output obtained per unit of production factor. In this report, it is used to express amount of product generated per unit of livestock and time (e.g. kg milk per cow per year).
Replacement rate	The percentage of adult animals in the herd replaced by younger adult animals.
Scavenging	Backyard animals roaming freely in search of feed sources (e.g. food scraps, insects).
Soil liming	The application of lime and other calcium fertilizers to the soil to eliminate excess acidity.
Urea treatment	The application of urea to forages under airtight conditions. Ammonia is formed from the urea and the alkaline conditions which compromise cell wall conformation and improve intake and digestibility of low quality roughages or crop residues.

KEY MESSAGES OF CHAPTER 1

- Scientific evidence shows that collective action is falling short in terms of addressing climate change effectively. Renewed efforts and commitments from all sectors are required.

- As a large user of natural resources and contributor to climate change, the livestock sector needs to address its environmental footprint.

- The sector faces the difficult challenge of having to reduce its GHG emissions while responding to a significant demand growth for livestock products (projected to be +70 percent between 2005 and 2050), driven by a growing world population (9.6 billion by 2050), rising affluence and urbanization.

INTRODUCTION

World population will grow from 7.2 billion today to 9.6 billion in 2050. Population growth, growing incomes and urbanization combine to pose unprecedented challenges to food and agriculture systems, while the natural resources necessary to support global food and non-food production and provision of services from agriculture will not grow. Driven by strong demand from an emerging global middle class, diets will become richer and increasingly diversified, and growth in animal-source foods will be particularly strong; the demand for meat and milk in 2050 is projected to grow by 73 and 58 percent, respectively, from their levels in 2010 (FAO, 2011c).

The natural resources to sustain that growth are strained. Currently, agriculture plays an important role in global environmental issues, such as climate change, land degradation, water pollution and biodiversity loss. Future growth in production must be accommodated within the growing scarcity of natural resources, including land, water and nutrients, and waste and GHG emissions must be reduced.

Within agriculture, the livestock sector has come into focus because of its large interface with the environment. Traditionally, livestock was supply driven, converting waste material and other resources of limited alternative use into edible products and other goods and services. Its size was relatively limited and so were the environmental impacts. However, since the livestock sector has become increasingly demand-driven, growth has been faster and the sector now competes for natural resources with other sectors. Environmental impacts have become greater and the sector is often pointed out as being particularly resource-hungry.

Three concerns have emerged. First, the production of animal protein, particularly when fed on dedicated crops, is typically less efficient than the production of equivalent amounts of plant protein. Second, extensive livestock are often kept in remote environments where deforestation and land degradation reflect weaknesses in institutions and policies. Lastly, intensive livestock production tends to cluster in locations with cost advantages (often close to cities or ports) where insufficient land is available for the recycling of waste from livestock, leading to nutrient overloads and pollution.

However, a large part of the livestock sector remains supply-driven. Hundreds of millions of pastoralists and smallholders depend on livestock for their daily survival and extra income and food. Such traditional forms of livestock production have come under increasing pressure resulting from competition over land and water resources.

Traditional systems are often difficult to intensify, and typically suffer from a lack of competitiveness, infrastructures and market barriers in accessing modern value chains. While the presence of large numbers of poor people engaged in the livestock sector makes efforts aimed at improved environmental performance more challenging, that same fact also offers an opportunity. Investing in efficient production and compensating herders and livestock keepers for environmental service provision, such as water services, biodiversity protection and carbon capture, can create both social and environmental gains if appropriate incentive mechanisms can be found.

This report focuses on the contribution of livestock to climate change. While this is only one of several aspects of environmental sustainability, it has been a question of particular interest and debate. In 2006, FAO published *Livestock's long shadow – Environmental issues and options* that provided a global, aggregated view showing that the impact of livestock on the environment was much larger than commonly thought. Importantly, the more indirect roles of livestock in environmental degradation, as a driver of deforestation and degradation, agricultural intensification and industrialization, and as a competitor for natural resources, have come into focus. The *Livestock's long shadow* publication provided aggregate perspectives on the role of livestock in climate change, water and biodiversity. However, it was the climate change issue and the estimated 18 percent contribution of livestock to total GHG emissions that received most attention.

Tackling climate change has now become extremely urgent. The first decade of the twenty-first century was the warmest on record (National Aeronautics and Space Administration - NASA, January 2013), with 2010 and 2005 ranking as the hottest years on record. In November 2012, the World Bank warned that the planet is on track for a 4 °C warmer world with devastating effects in the form of extreme heatwaves, declining global food stocks and sea level rise (World Bank, 2012), and, ultimately, severe risks for vital human support systems. It urged that warming be held below 2 °C.[3] But the door of climate targets is closing (Stocker, 2013): the later the global emission reduction takes place, the greater the effort needed to achieve a given stabilization scenario. Assuming a maximum GHG emission reduction rate of 5 percent per year, the 1.5 °C target is probably already unachievable and the 2 °C target will also be missed if no action is taken prior to 2027.

While the conclusions of climate change science are clear and the impact increasingly visible, actions to address climate change fall short of what is required. The most recent 'gap report' of the United Nations Environment Programme (UNEP) shows that current country pledges to reduce GHG emissions will deliver no more than one-third of what is needed by 2020 to avoid a 2 °C rise in global temperature.

There is a myriad of diverse production situations, environmental impact and possible intervention strategies, and any global assessment is a simplification of reality. Mitigation needs to work in local conditions. Critically, such interventions need to address the social and poverty dimension of livestock, and livestock-dependent livelihoods cannot be put at risk when alternatives are lacking.

This report provides a snapshot of the current state of FAO's assessment work on livestock's contribution to climate change. It draws on three technical reports addressing emissions from dairy cattle (FAO, 2010a), ruminants (FAO, 2013a) and monogastrics (FAO, 2013b). It provides an overview of results and explores main mitigation potential and options on the production side. It does not discuss possible mitigation options on the consumption side.

In a complex analysis such as this, results are never definitive, but rather the best assessment that could be made with available resources, and subject to improvement.

The assessment presented here is the result of a collaborative work on different livestock com-

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[3] The global community has committed itself to limit the average global surface temperature increase at below 2 °C over the pre-industrial average.

modities carried out over recent years and with contributions from public and private organizations. It is meant to inform and enrich the discussion about livestock and resource use, and will hopefully trigger critical inputs and suggestions for further improvement and refinement.

This report comes at a time when the urgent need to address livestock resource use issues is increasingly realized and a wide range of stakeholders, including governments, the private sector, producer groups, research institutions and intergovernmental organizations, have committed to tackle resource use issues related to the livestock sector.

KEY MESSAGES OF CHAPTER 2

- This assessment is based on the newly developed Global Livestock Environment Assessment Model (GLEAM). This new modelling framework enables the production of disaggregated estimates of GHG emissions and emission intensities for the main commodities, farming systems and world regions. GLEAM quantifies GHG emissions for geographically defined spatial units (cells measuring 5 km x 5 km at the equator), on the basis of modules reproducing the main elements of livestock supply chains.

- Important geographical patterns such as soil quality, climate and land use are encompassed representing a major improvement compared to other assessments which relied on national averages.

- The analysis uses the life cycle assessment (LCA) method for the identification of all main emission sources along supply chains, starting from land use and the production of feed through to animal production to processing and transportation of products to the retail point.

- The three major GHGs emitted from food and agriculture chains are covered – CH_4, N_2O and CO_2.

- The livestock species included in the assessment are large ruminants (cattle and buffalo), small ruminants (sheep and goats), and pigs and poultry (chicken, turkey, duck and geese).

- GLEAM uses spatially explicit information from a wide range of sources and relies predominantly on the IPCC (2006) guidelines to compute emissions.

- The year of reference is 2005, as this is the year with the most recent complete set of data required to carry out the analysis. To capture recent trends in land-use change (LUC), more recent data were also used.

- The robustness of model assumptions were tested through sensitivity analysis and results were compared for plausibility with other studies.

- The mitigation potential from soil carbon sequestration in grasslands was estimated outside of the GLEAM framework using the Century and Daycent ecosystem models; dedicated grassland ecosystem models.

METHODS

2.1 INTRODUCTION

GLEAM was developed to help improve the understanding of livestock GHG emissions along supply chains, and to identify and prioritize areas of intervention to lower sector emissions.

The absence of a tool that could enable a comprehensive and consistent analysis of the emissions of global livestock production motivated the development of this novel modelling framework.

GLEAM was also developed with the objective of testing the effectiveness of mitigation practices and packages that are suitable for adoption in different production systems, subject, of course to their economic and institutional feasibility. In this respect, GLEAM has a high level of quantitative detail on herd production functions and resource flows, that is well suited to the bio-economic modelling work needed to support these broader assessments. This could be achieved either through the direct inclusion of economic data and parameters in the GLEAM framework, or by coupling GLEAM with existing economic models, such as GTAP, CAPRI, GLOBIOM or IMPACT (Hertel *et al.*, 1999; Britz & Witzke, 2008; Havlik *et al.*, 2011; Rosegrant *et al.*, 2008) .

GLEAM is developed at FAO, with support from partner organizations and related initiatives, such as the MICCA programme, and LEAP.[4] LEAP provides a platform for the harmonization of metrics and methods to monitor the environmental performance of the livestock supply chains and is instrumental in the development of methods and assumptions underpinning GLEAM.

In its current form, the model only quantifies GHG emissions, but it was developed with the intention to include other environmental categories, such as nutrient, water and land use. The basic data structure and modules that comprise the model are in place to support these developments, which will benefit from the work carried out in the context of LEAP.

2.2 GLOBAL LIVESTOCK ENVIRONMENTAL ASSESSMENT MODEL (GLEAM)[5]

Overview

GLEAM represents the main activities of global livestock supply chains, with the aim of exploring the environmental implications of production practices for the main commodities, farming systems and regions.

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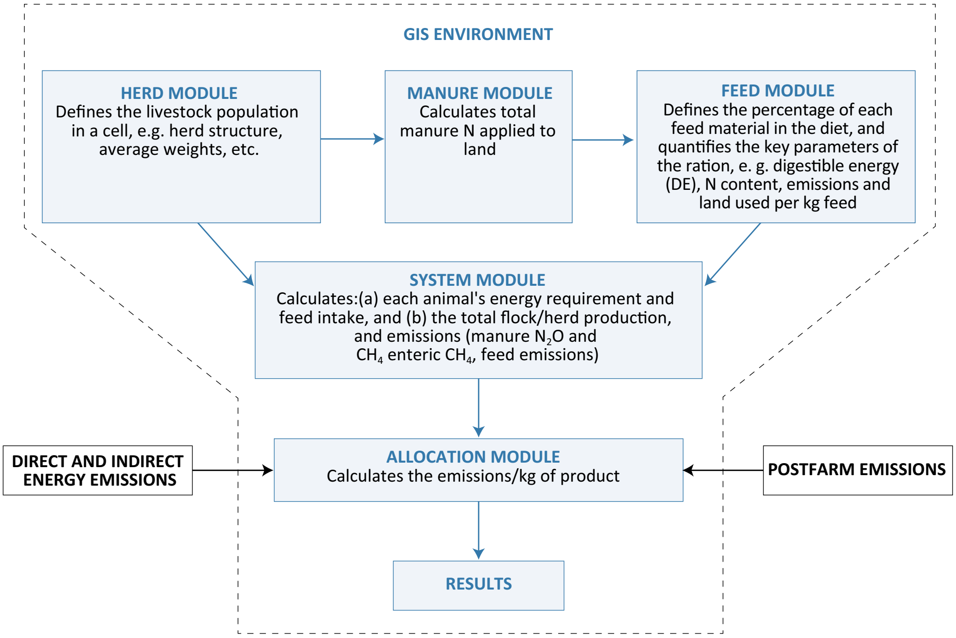
[4] www.fao.org/partnerships/leap

[5] For a detailed presentation of GLEAM and associated database, see FAO (2013a and 2013b).

FIGURE 1. Overview of the GLEAM modules and computation flows



Source: Authors.

GLEAM is built on five modules reproducing the main elements of livestock supply chains: the *herd module*, the *feed module*, the *manure module*, the *system module* and the *allocation module*. The overall model structure is shown in Figure 1.

The *herd module* starts with the total number of animals of a given species and system within a GIS grid cell. It attributes animals to the different farming systems, determines the herd structure (i.e. the number of animals in each cohort and the rate at which animals move between cohorts) and the characteristics of the average animal in each cohort (e.g. weight and growth rate).

The herd structure and animal characteristics are subsequently used in the *system module* to calculate the energy requirements of each animal type, and the total amount of meat, milk and eggs produced in the GIS cell each year. Herd module information is also used in the *manure module* to produce estimates of manure production. In parallel, the *feed module* calculates key feed parameters, i.e. the composition, nutritional content and emissions per kg of feed ration. Further information is contained in the Appendix.

The information on herd structure, manure, animal and feed characteristics is then used in the *system module* to calculate the total annual production, as well as emissions arising from manure management, enteric fermentation and feed production. The total emissions at the farmgate are calculated by adding the energy use emissions arising from direct on-farm energy use, the construction of farm buildings and manufacture of equipment.

The total emissions at the farmgate are then allocated to co-products and services in the *allocation module*, and emission intensities at farmgate are then calculated. The postfarm emissions are

TABLE 1. Sources of GHG emissions considered in this assessment

Supply chain	Activity	GHG	Included	Excluded
UPSTREAM	Feed production	N_2O	Direct and indirect N_2O from: • Application of synthetic N • Application of manure • Direct deposition of manure by grazing and scavenging animals • Crop residue management	• N_2O losses related to changes in C stocks • Biomass burning • Biological fixation • Emissions from non-N fertilizers and lime
		CO_2 N_2O CH_4	• Energy use in field operations • Energy use in feed transport and processing • Fertilizer manufacture • Feed blending • Production of non-crop feedstuff (fishmeal, lime and synthetic amino acids) • CH_4 from flooded rice cultivation • Land-use change related to soybean cultivation	• Changes in carbon stocks from land use under constant management practices
	Non-feed production	CO_2	• Embedded energy related to manufacture of on-farm buildings and equipment	• Production of cleaning agents, antibiotics and pharmaceuticals
ANIMAL PRODUTION UNIT	Livestock production	CH_4	• Enteric fermentation • Manure management	
		N_2O	• Direct and indirect N_2O from manure management	
		CO_2	• Direct on-farm energy use for livestock (e.g. cooling, ventilation and heating)	
DOWNSTREAM	Post farmgate	CO_2 CH_4 HFCs	• Transport of live animals and products to slaughter and processing plant • Transport of processed products to retail point • Refrigeration during transport and processing • Primary processing of meat into carcasses or meat cuts and eggs • Manufacture of packaging	• On-site waste water treatment • Emissions from animal waste or avoided emissions from on-site energy generation from waste • Emissions related to slaughter by-products (e.g. rendering material, offal, hides and skin) • Retail and post-retail energy use • Waste disposal at retail and post-retail stages[1]

[1] Food losses are not included.

Source: Authors.

computed separately and finally added to the latter to obtain overall emissions intensities.

Sources of emissions

The model considers all the main sources of emissions along livestock supply chains (Table 1); only emissions that are generally reported as marginal were omitted. Changes in soil and vegetation carbon stocks not involving land-use change can be significant but are not included because of the lack of information and reliable modelling frameworks. The effect of this simplification has nevertheless been explored in the case of the European Union (EU) in FAO (2013a). The analysis shows that permanent grasslands may represent a sink of 11.5 ± 69.0 million tonnes CO_2-eq per year, or 3 ± 18 percent of GHG emissions from the ruminant sector in the European Union. Other potentially significant emission pathways excluded because of data limitations are those associated with the labour force and the provision of services and assistance to stakeholders along the chain.

TABLE 2. Summary of ruminant production systems

System	Characteristics
Grassland-based (or grazing) 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 ha of agricultural land
Mixed 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

Source: FAO, 2011b.

TABLE 3. Summary of pig production systems

System	Housing	Characteristics
Industrial	Fully enclosed: slatted concrete floor, steel roof and support, brick, concrete, steel or wood walls	Fully market-oriented; high capital input requirements (including infrastructure, buildings, equipment); high level of overall herd performance; purchased non-local feed in diet or on-farm intensively produced feed
Intermediate	Partially enclosed: no walls (or made of a local material if present), solid concrete floor, steel roof and support	Fully market-oriented; medium capital input requirements; reduced level of overall herd performance (compared with industrial); locally-sourced feed materials constitute 30 to 50 percent of the ration
Backyard	Partially enclosed: no concrete floor, or if any pavement is present, made with local material. Roof and support made of local materials (e.g. mud bricks, thatch, timber)	Mainly subsistence driven or for local markets; level of capital inputs reduced to the minimum; herd performance lower than in commercial systems; feed contains maximum 20 percent of purchased non-local feed; high shares of swill, scavenging and locally-sourced feeds

Source: Authors.

Land-use change emissions

Land-use change is a highly complex process. It results from the interaction of diverse drivers which may be direct or indirect and can involve numerous transitions, such as clearing, grazing, cultivation, abandonment and secondary forest re-growth. From a climate change point of view, deforestation is the land-use change process generating most GHG emissions (IPCC, 2007). The debate surrounding the key drivers of deforestation is ongoing and so is the attribution of GHG emissions to these drivers.

In the current version of GLEAM, land-use changes are considered as the transformation of forest to arable land for feed crops and that of forest to pasture. Emissions are generally quantified according to IPCC Tier I guidelines (IPCC, 2006).

The analysis of the expansion of feed crops was limited to soybean production in Brazil and Argentina. This decision results from the observation of trends in land-use transitions and crop expansions: over the 1990–2006[6] period, which is used as the reference time period in this study, the main global cropland expansions were for maize and soybean production, but only in Latin America was this expansion directly linked to decrease in forest area. Within Latin America, 90 percent of the soybean area expansion that took place over the period 1990–2006 happened in Brazil and Argentina (which accounts for 91 percent of the total soybean area in the region).

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[6] 1990 was chosen as the initial year because it was the most recent available year with a consistent forest dataset from the FAOSTAT database. Practically, his choice of 1990 discounts four years of land-use change-related emissions, compared with the 20-year timeframe recommended by IPCC (IPCC, 2006).

TABLE 4. Summary of chicken production systems

System	Housing	Characteristics
Broilers	Broilers assumed to be primarily loosely housed on litter, with automatic feed and water provision	Fully market-oriented; high capital input requirements (including Infrastructure, buildings, equipment); high level of overall flock productivity; purchased non-local feed or on-farm intensively produced feed
Layers	Layers housed in a variety of cage, barn and free-range systems, with automatic feed and water provision	Fully market-oriented; high capital input requirements (including infrastructure, buildings and equipment); high level of overall flock productivity; purchased non-local feed or on-farm intensively produced feed
Backyard	Simple housing using local wood, bamboo, clay, leaf material and handmade construction resources for supports (columns, rafters, roof frame) plus scrap wire netting walls and scrap iron for roof. When cages are used, these are made of local material or scrap wire	Animals producing meat and eggs for the owner and local market, living freely. Diet consists of swill and scavenging (20 to 40 percent) and locally-produced feeds (60 to 80 percent)

Source: Authors.

Emissions from deforestation associated with pasture expansion were quantified for Latin America only. This simplification results from the observation that, during the period 1990–2006, significant pasture expansions and simultaneous forest area decrease occurred in Latin America and Africa. However, grazing does not appear to be a significant driver of deforestation in Africa. In Latin America, the quantification of emissions was limited to the four countries accounting for over 97 percent of the regional area converted from forest to pasture (i.e. Brazil, Chile, Nicaragua and Paraguay).

GHG emissions related to land-use change were attributed to the systems and regions that use feed resources associated with deforestation. Trade matrices were used to track international flows of soybean and soybean cake and to estimate the share of soybean products from deforested areas in the ration of animals. Emissions associated with the expansion of pasture into forest areas in Latin America were attributed to beef production in those countries in which the conversion occurred.

Further explanations and sensitivity analyses are available in FAO (2013a) and FAO (2013b).

Supply chains

GLEAM incorporates over 14 000 discrete supply chains, defined here as unique combinations of commodity, farming system, country and agro-ecological zone. The geographical area corresponding to each of these sets is further decomposed into GLEAM production units: grid cells, or pixels, with a resolution of 3 arc minutes, or ca. 5 km x 5 km at the equator.

The model differentiates the 11 main livestock commodities: meat and milk from cattle, sheep, goats and buffalo; meat from pigs and meat and eggs from chickens. Ruminant production is differentiated into mixed and grazing systems; pig production into backyard, intermediate and industrial systems and chicken production into backyard, layers and broilers (Tables 2, 3 and 4).

Allocation

Where physical relationships alone cannot be established or used as a basis for differentiating emission fluxes, emissions should be allocated in a way that reflects other fundamental relationships. The most commonly used approach is economic allocation which, in the context of jointly produced products, allocates emissions to each product according to its share of the product's combined economic value. Other parameters, such as weight or protein content can also be used (Cederberg and Stadig, 2003). The allocation techniques used in this assessment to apportion emissions to products and services are summarized below:

- Among edible products (e.g. meat and eggs; beef and milk), the allocation is based on protein content.
- Between edible and non-edible products (e.g. milk, meat and fibre), the allocation is based on economic value of outputs.
- No emissions are allocated to slaughter by-products (e.g. offal, skins, blood) since the use of by-products and their value are subject to high spatial and temporal variability and are poorly documented on a global scale. FAO (2013a) and (2013b) explore the impact of allocating emissions to slaughter by-products.
- For manure, the allocation is based on subdivision of production processes:
  - emissions from manure storage are entirely allocated to the livestock sector;
  - emissions from manure applied to feed and deposited on pasture are attributed to the livestock sector and allocated to feed materials based on mass harvested and relative economic value;
  - emissions from manure not applied to feed crops or pasture are considered to exit the livestock sector and, thus, not allocated to livestock commodities.
- For services (e.g. animal draught power), the allocation is based on extra lifetime gross energy requirements for labour, and emissions are deducted from the overall livestock emissions.
- No emissions are allocated to the capital function of livestock.

Data

GLEAM utilizes geo-referenced data to compute emissions from the livestock sector. Data on production practices and productivity were collected at different levels of aggregation: production systems, country levels, agro-ecological zones, or a combination thereof (e.g. information on manure storage in developing countries was available for a combination of production systems and agro-ecological zones). Additional data, such as livestock numbers, pasture and availability of feedstuffs was available in the form of GIS grids (raster layers). GIS can store observed data for specific locations and it can model new information from these data, as well as calculate regional summaries such as total area, emissions, etc. The use of GIS thus permits incorporation of spatial heterogeneity into the modelling process. In this way, emissions can be estimated for any location of the globe, using the most accurate information available at this scale of analysis, and then aggregated along the desired category, such as farming systems, country group, commodity and animal species. Average emission intensities can thus be generated at various scales, from cell level production units within GLEAM to the global level.

Data collection involved extensive research of databases, literature sources, expert opinion and access to public and commercially available life cycle inventory packages such as Ecoinvent. Assumptions were made when data could not be obtained. The study's main data sources included:

- Gridded Livestock of the World (FAO, 2007);
- National Inventory Reports of Annex I countries (UNFCCC, 2009a);
- National Communications of non-Annex I countries (UNFCCC, 2009b);
- geo-referenced databases on feed availability from the International Food Policy Research Institute (IFPRI) (You *et al*., 2010);
- satellite data on gross primary production;
- Life Cycle Inventory data from SIK (Flysjö *et al.*, 2008), and Wageningen University, the Netherlands (I. de Boer, personal communication);
- reports from the Consultative Group on International Agriculatural Research (CGIAR);
- statistics from FAO (FAOSTAT, 2009);
- peer-reviewed journals.

Uncertainty analysis

For such a global assessment, simplifications, assumptions and methodological choices need to be made that introduce a degree of uncertainty in the results. As summarized below, several sensitivity analyses were conducted on specific elements of GLEAM in order to understand the effects of these choices.

Credit: ©FAO/Ami Vitale

In this assessment, emissions arising from land-use change were calculated using IPCC recommendations (IPCC, 2006). Three alternative methods were tested to account for methodological uncertainties and to assess the impact of recent reductions of deforestation rates in Latin America and the Caribbean (cf. section 4.6).

A partial sensitivity analysis was also carried out on the final results. It was performed for selected countries and production systems and focused on the parameters that were most likely to have a significant influence on emission intensities, and which were thought to have a high degree of uncertainty or inherent variability. The analysis conducted for a few countries and systems showed that the 95 percent interval of confidence for ruminants is about ± 50 percent, while it is between ± 20 and 30 percent for monogastrics. The higher level of uncertainties associated with the ruminant estimates relates to variability in herd parameters and land-use change emissions.

Validation

There are a growing number of local and regional LCA studies with which the results in this study can be compared, although some systems and regions have not yet been covered. However, the comparison is not straightforward because different studies use different methodologies. In particular, results need to be corrected to account for differences in scope (i.e. the system boundaries used and the specific emissions sources included) and functional units before they can be compared.

The results of the assessment were compared with over 50 other LCA studies of livestock GHG emissions. Most of the discrepancies can be explained with reference to differences in approaches used, and assumptions made regarding feed composition and digestibility, animal weights, land-use change emissions, manure management practices and rules for allocating emissions to co-products. Despite these differences, the results of this assessment were generally found to be within the range of the results in the literature.

2.3 MODELLING CARBON SEQUESTRATION POTENTIAL IN GRASSLANDS

The carbon sequestration potential of different management strategies in the world's grasslands (i.e. rangelands and pastures) was estimated outside of the GLEAM framework using the Century and Daycent ecosystem models – dedicated grassland ecosystem models.

The Century and Daycent ecosystem models

The Century model simulates plant and soil carbon (C), nitrogen (N), phosphorus (P) and sulfur (S) dynamics (Parton *et al.*, 1987) and it has been validated against production and soil C stock (and stock change) observations in a variety of grazing land ecosystems, since its development in the 1980s. The Century model was used to assess the carbon sequestration potential for improved grazing management. The Daycent model (Parton *et al.*, 1998) is the daily version of the Century ecosystem model, and it was used to assess both the soil carbon sequestration potential and N_2O fluxes, from legume sowing and grassland fertilization activities. The Daycent model is better able to represent N_2O fluxes from different ecosystems.

Assessment of soil carbon sequestration

Both the Century and Daycent ecosystem models were run over a 20-year time frame, to assess the scenarios outlined below.

1. **Baseline scenario:** To represent the baseline or current grazing conditions, the Century and Daycent models were run using data on climate observations and estimates of the rates of forage off-take by ruminants. These rates, which are one of the main management drivers in the Century and Daycent models, were based on the ratio of annual ruminant roughage consumption levels from the GLEAM model and annual forage production (or above ground net primary productivity), which are derived from the Century and Daycent models.
2. **Improved grazing scenario:** In comparison to the baseline scenario, forage off-take rates were adjusted either upwards or downwards to maximize annual forage production. As with the baseline scenario, these consumption levels were based on spatially referenced ruminant roughage consumption levels from the GLEAM model. The improved grazing scenario was applied to all of the world's grasslands in which domesticated grazing ruminants are present.
3. **Legume sowing scenario:** The mitigation potential of legume sowing was assessed by estimating soil carbon sequestration minus increases in N_2O emissions from legumes. This practice was only applied on the relatively wet grassland areas (e.g. mesic pastures) that do not fall with the native vegetation biomes that comprise the world's rangelands. Legumes were assumed to be oversown with grass to achieve approximately 20 percent cover, and to persist over the course of the simulation with no re-sowing or additional inputs.
4. **Fertilization scenario:** The mitigation potential of grassland fertilization was also assessed by estimating soil carbon sequestration in grasslands minus increases in N_2O emissions. Fertilization was also only applied in the mesic pastures areas that do not fall with the native vegetation biomes that comprise the world's rangelands. Nitrogen fertilizer was assumed to be added as ammonium-nitrate, with input rates ranging from 0 to 140 kg N ha^{-1} in 20 kg N ha^{-1} increments.

All management scenarios were assessed over a 20-year period using weather data from 1987–2006, on the assumption that climate change-induced changes in GHG fluxes over the next decade will be modest in comparison with management effects.

Of the three mitigation scenarios, only improved grazing and legume sowing were estimated to have net positive mitigation potentials at the global level. For the fertilization scenario, the additional N_2O emissions from N fertilizer were estimated to offset all related increases in soil carbon stocks.

Grassland area data

Century model runs were conducted at 0.5 degree resolution, corresponding with available climate data. In order to area-correct the results, a map was created to scale these results to match the actual area of grassland within each pixel. In the first step, grassland and woodland land cover data from the Global Agro-Ecological Zone (GAEZ) dataset produced by FAO and International Institute for Applied Systems Analysis (IIASA) were used to define the maximum spatial extent of the world's grasslands.[7] In the second step, this aggregated GAEZ spatial layer, was adjusted to match the average area of permanent pastures and meadows reported in FAOSTAT in the year 2005.[8] The resulting total grassland area following this procedure was approximately 3 billion ha. Additional steps were then taken to apportion this aggregate grassland area in rangeland areas and non-rangeland areas (e.g. mesic pastures). For this step, rangelands were defined as all of the grazing land areas falling within the native grassland, shrubland and savannah biomes in a biome database created for a global model inter-comparison project (Cramer *et al.*, 1999). The residual grassland areas comprise the mesic pasture areas on which the legume sowing and fertilizer scenarios were applied.

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[7] http://gaez.fao.org/Main

[8] http://faostat.fao.org/site/377/default.aspx

KEY MESSAGES OF CHAPTER 3

- With GHG emissions along livestock supply chains estimated at 7.1 gigatonnes CO_2-eq per annum, representing 14.5 percent of all human-induced emissions, the livestock sector plays an important role in climate change.

- Feed production and processing and enteric fermentation from ruminants are the two main sources of emissions, representing 45 and 39 percent of sector emissions. Manure storage and processing represent 10 percent. The remainder is attributable to the processing and transportation of animal products.

- Included in feed production, land-use change – the expansion of pasture and feed crops into forests – accounts for about 9 percent of sector emissions.

- Cutting across categories, the consumption of fossil fuels along the sector supply chains accounts for about 20 percent of emissions.

- The animal commodities contributing most of the sector's GHG emissions are beef and cattle milk, contributing 41 and 20 percent of the sector's emissions respectively. Methane from rumination plays an important role.

- Pig meat and poultry meat and eggs contribute respectively 9 percent and 8 percent to the sector's emissions.

THE AGGREGATE PICTURE

3.1 OVERALL EMISSIONS

Important contribution to total human-induced emissions

Total GHG emissions from livestock supply chains are estimated at 7.1 gigatonnes CO_2-eq per annum for the 2005 reference period. They represent 14.5 percent of all human-induced emissions using the most recent IPCC estimates for total anthropogenic emissions (49 gigatonnes CO_2-eq for the year 2004; IPCC, 2007).

This absolute figure is in line with FAO's previous assessment, *Livestock's long shadow*, published in 2006 (FAO, 2006), although it is based on a much more detailed analysis involving major methodological refinements and improved data sets (Chapter 2). Relative contributions cannot be compared because reference periods differ. The 2006 assessment compared its estimate (based on a 2001 to 2004 reference period) with the total CH_4, N_2O and CO_2 anthropogenic emissions estimate provided by the World Resource Institute (WRI) for the year 2000.

Methane: the most emitted gas

About 44 percent of the sector's emissions are in the form of CH_4. The remaining part is almost equally shared between N_2O (29 percent) and CO_2 (27 percent). Livestock supply chains emit:[9]

- 2 gigatonnes CO_2-eq of CO_2 per annum, or 5 percent of anthropogenic CO_2 emissions (IPCC, 2007)
- 3.1 gigatonnes CO_2-eq of CH_4 per annum, or 44 percent of anthropogenic CH_4 emissions (IPCC, 2007)
- 2 gigatonnes CO_2-eq of N_2O per annum, or 53 percent of anthropogenic N_2O emissions (IPCC, 2007)

Emissions of hydrofluorocarbons (HFCs) are marginal on a global scale.

3.2 EMISSIONS BY SPECIES AND COMMODITIES

Cattle contribute most to emissions

Cattle are the main contributor to the sector's emissions with about 4.6 gigatonnes CO_2-eq, representing 65 percent of sector emissions. Beef cattle (producing meat and non-edible outputs) and dairy cattle (producing both meat and milk, in addition to non-edible outputs) generate similar amounts of GHG emissions.

Pigs, poultry, buffaloes and small ruminants have much lower emission levels, with each representing between 7 and 10 percent of sector emissions (see Figure 2).

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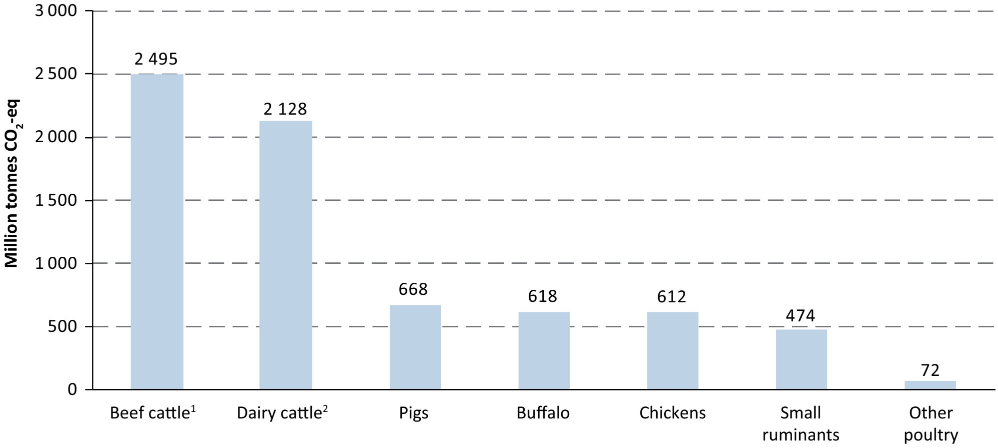
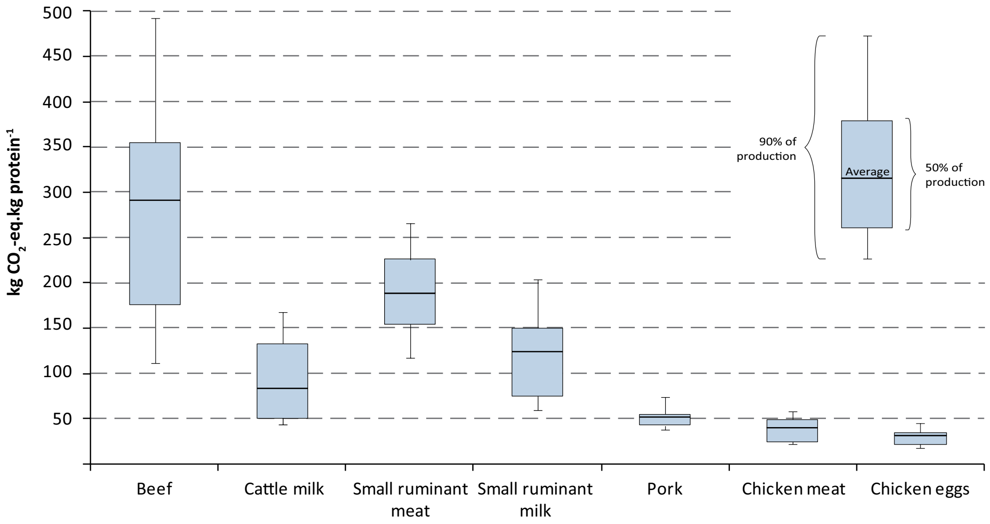
[9] GHG emission values are computed in GLEAM for 2005, while IPCC estimates of total anthropogenic emissions are for 2004.

FIGURE 2. Global estimates of emissions by species*



*Includes emissions attributed to edible products and to other goods and services, such as draught power and wool.
[1] Producing meat and non-edible outputs.
[2] Producing milk and meat as well as non-edible outputs.
Source: GLEAM.

FIGURE 3. Global emission intensities by commodity



Source: GLEAM.

Beef: commodity with highest total emissions and emission intensities

Beef contribute 2.9 gigatonnes CO_2-eq, or 41 percent, and cattle milk 1.4 gigatonnes CO_2-eq, or 20 percent, of total sector emissions. They are followed by pig meat, with 0.7 gigatonnes CO_2-eq, or 9 percent of emissions, buffalo milk and meat (8 percent), chicken meat and eggs (8 percent), and small ruminant milk and meat (6 percent). The rest are emissions from other poultry species and non-edible products.

When emissions are expressed on a per protein basis, beef is the commodity with the highest emission intensity (amount of GHGs emitted per unit of output produced), with an average of over 300 kg CO_2-eq per kg of protein; followed by meat and milk from small ruminants, with averages of 165 and 112 kg CO_2-eq per kg of protein, respectively. Cow milk,[10] chicken products and pork have lower global average emission intensities, all below 100 kg CO_2-eq per kg of edible protein (Figure 3).

Large differences in emission intensity between producers

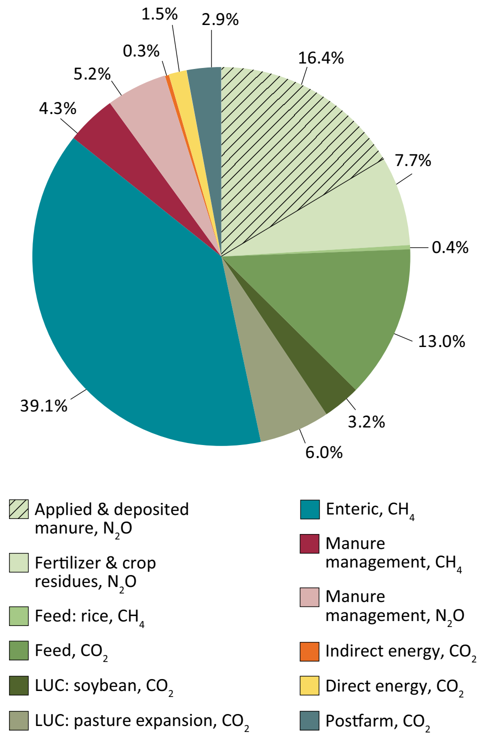
For ruminant products especially, but also for pork and chicken meat and eggs, emission intensities vary greatly among producers (Figure 3). Different agro-ecological conditions, farming practices and supply chain management explain this heterogeneity, observed both within and across production systems. It is within this variability – or gap between producers with highest emission intensity and those with lowest emission intensity – that many mitigation options can be found (Chapter 5 contains a detailed discussion).

3.3 MAIN SOURCES OF EMISSIONS

Emissions from the production, processing and transport of feed account for about 45 percent of sector emissions. The fertilization of feed crops and deposition of manure on pastures generate substantial amounts of N_2O emissions, representing together about half of feed emissions (i.e. one-quarter of the sector's overall emissions). About one-quarter of feed emissions (less than 10 percent of sector emissions) are related to land-use change (Figure 4).

Among feed materials, grass and other fresh roughages account for about half of the emissions, mostly from manure deposition on pasture and land-use change. Crops produced for feed account for an additional quarter of emissions, and all other feed materials (crop by-products, crop residues, fish meal and supplements) for the remaining quarter (Figure 4).

FIGURE 4. Global emissions from livestock supply chains by category of emissions



Enteric fermentation is the second largest source of emissions, contributing about 40 percent to total emissions. Cattle emit most of the enteric CH_4 (77 percent), followed by buffalos (13 percent) and small ruminants (10 percent).

Methane and N_2O emissions from manure storage and processing (application and deposition excluded) represent about 10 percent of the sector's emissions.

Emissions associated with energy consumption (directly or indirectly related to fossil fuel) are mostly related to feed production, and fertilizer manufacturing, in particular. When added up along the chains, energy use contributes about 20 percent of total sector emissions.

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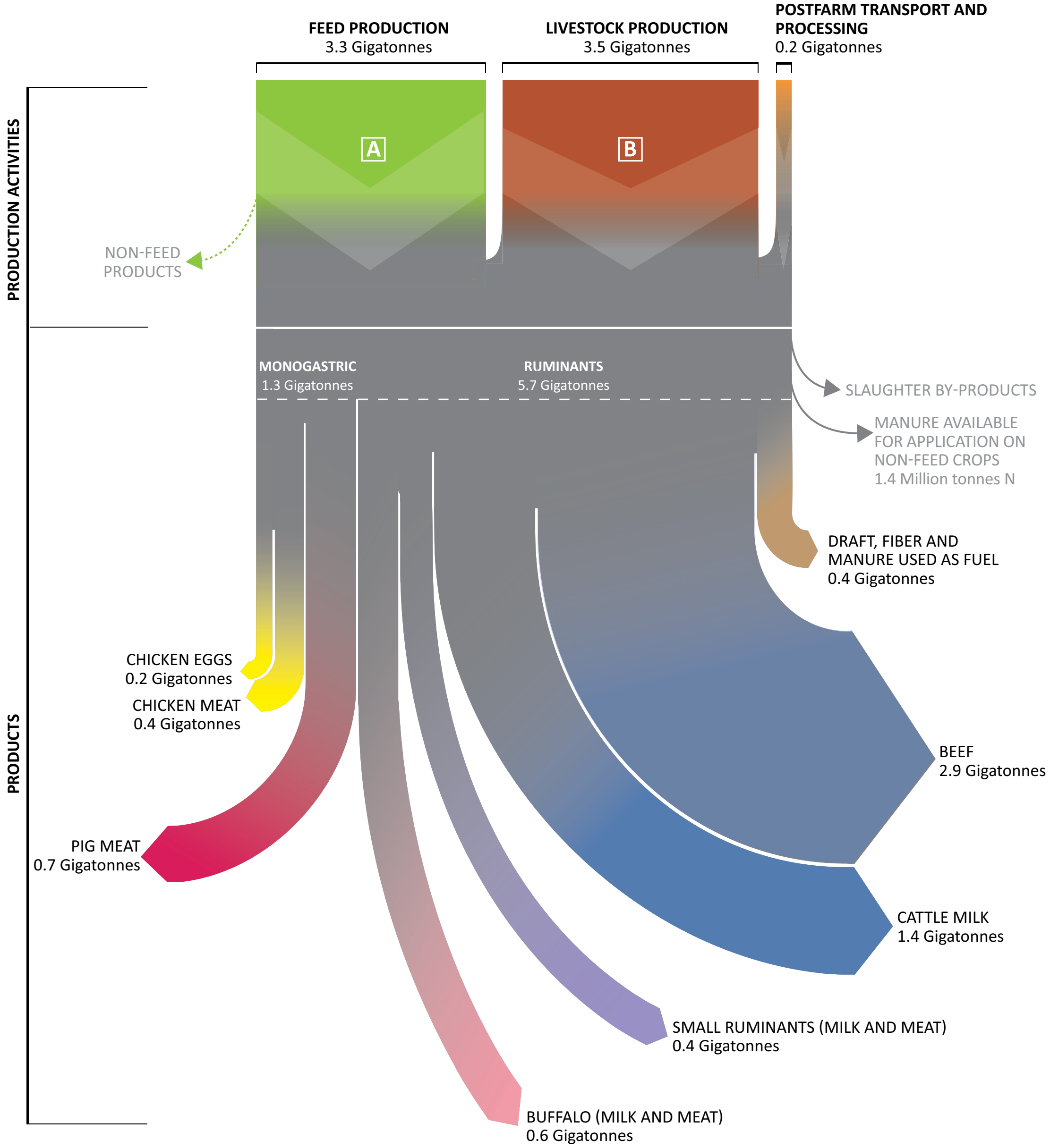
[10] Throughout this document, milk units are corrected for fat and protein content – see FPCM in Glossary.

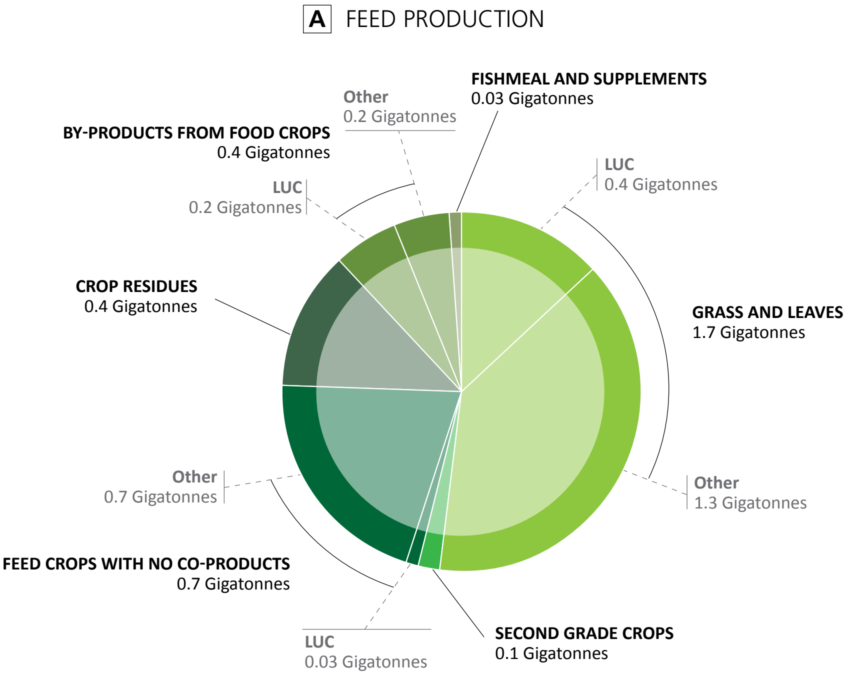
FIGURE 5. GHG emissions from global livestock supply chains, by production activities and products

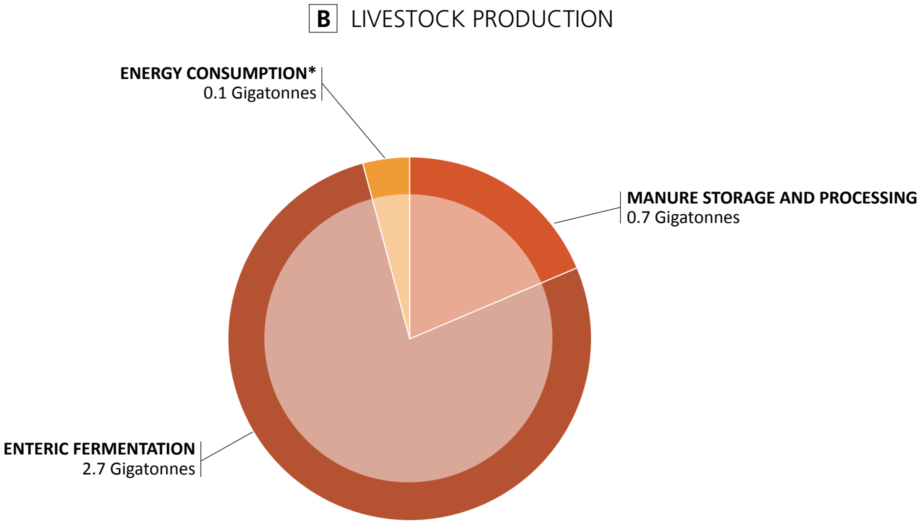


GHG EMISSIONS FROM GLOBAL LIVESTOCK SUPPLY CHAINS, BY PRODUCTION ACTIVITIES AND PRODUCTS

Different types of feed crops are identified: second grade crops (food crops that do not match quality standards for human consumption and that are fed to livestock), feed crops with no co-products (crops cultivated as feed, e.g. maize, barley), crop residues (residues from food of feed crops, e.g. maize stover, straw), and by-products from food crops (by-products from food production and processing, e.g. soybean cakes, bran). The arrow "non-feed products" reminds, that the emissions from the production of feed are shared with other sectors. For example, household food waste used to feed pigs in backyard systems are estimated to have an emission intensity of zero because emissions are entirely attributed to household food. In the same way, emissions related to crop residues (e.g. maize stover) are low because most of the emissions are attributed to the main product (maize grain).

No emissions could be allocated to slaughterhouse by-products (e.g. offal, skins, blood). Case studies show that by-products can add about 5 to 10 percent to the total revenue at slaughterhouse gate, for example for beef and pork in the Organisation for Economic Co-operation and Development (OECD) countries (FAO, 2013a and 2013b). Poultry other than chicken are not included in the graph.





*Embedded energy related to manufacture of on-farm building and equipment is included in this category.

Source: GLEAM.

BOX 1. MAIN EMISSION PATHWAYS

The bulk of GHG emissions originate from four main categories of processes: enteric fermentation, manure management, feed production and energy consumption.

Methane emissions from enteric fermentation. Ruminant animals (cattle, buffalo, sheep and goat) produce CH_4 as part of their digestive process. In their rumen (stomach), microbial fermentation breaks down carbohydrates into simple molecules that can be digested by the animals. Methane is a by-product of this process. Poorly digestible (i.e. fibrous) rations cause higher CH_4 emissions per unit of ingested energy. Non-ruminant species, such as pigs, also produce CH_4 but amounts are much lower by comparison. Enteric fermentation from cattle, buffalo, small ruminants and pigs, but not from poultry, is included in this assessment.

Methane and N_2O emissions from manure management. Manure contains two chemical components that can lead to GHG emissions during storage and processing: organic matter that can be converted into CH_4, and N that leads to nitrous oxide emissions. Methane is released from the anaerobic decomposition of organic material. This occurs mostly when manure is managed in liquid form, such as in deep lagoons or holding tanks. During storage and processing, nitrogen is mostly released in the atmosphere as ammonia (NH_3) that can be later transformed into N_2O (indirect emissions).

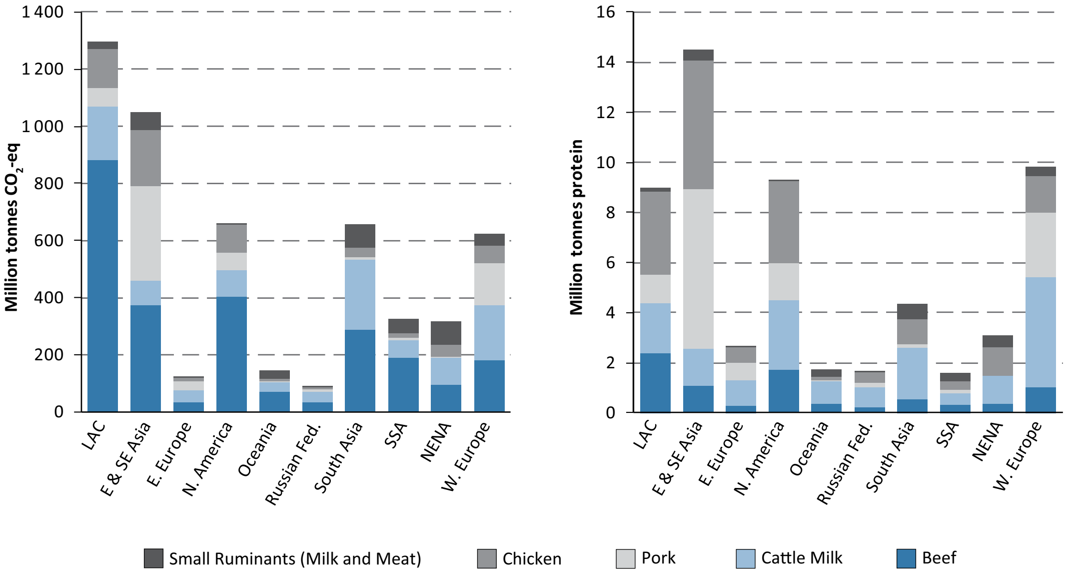
Carbon dioxide and N_2O emissions from feed production, processing and transport. Carbon dioxide emissions originate from the expansion of feed crops and pasture into natural habitats, which causes the oxidation of C in soil and vegetation. They also originate from the use of fossil fuel to manufacture fertilizer, and process and transport feed. The emissions of N_2O come from the use of fertilizers (organic or synthetic) for feed production and from the direct deposition of manure on pasture or during the management and application of manure on crop fields. Direct or indirect N_2O emissions can vary greatly according to temperature and humidity at the time of application and their quantification is thus subject to high uncertainty.

Carbon dioxide emissions from energy consumption. Energy consumption occurs along the entire livestock supply chains producing CO_2 emissions. At feed production level, energy consumption mostly relates to the production of fertilizers and to the use of machinery for crop management, harvesting, processing and transportation. Energy is also consumed on the animal production site, either directly through mechanized operations, or indirectly for the construction of buildings and of equipment. Finally, processing and transportation of animal commodities involve further energy use.

Throughout the report, emissions categories are indicated in the following ways in the legend accompanying Figures:

- Feed, N_2O including:
  - Fertilizer & crop residues, N_2O – emissions from fertilizer applied to feed crops and from the decomposition of crop residues;
  - Applied & deposited manure, N_2O – emissions from manure applied to feed crops and pasture or directly deposited on pastures by animals.
- Feed, CO_2 – emissions from the production, processing and transport of feed;
- LUC: soybean, CO_2 – emissions from the expansion of cropland for feed production;
- LUC: pasture expansion, CO_2 – emissions from the expansion of pasture;
- Feed: rice, CH_4 – emissions from rice cultivation for feed purposes;
- Enteric, CH_4 – emissions from enteric fermentation;
- Manure management, CH_4 – emissions from manure storage and processing (application and deposition excluded);
- Manure management, N_2O - emissions from manure storage and processing (application and deposition excluded);
- Direct energy, CO_2 – emissions from energy use on animal production unit (heating, ventilation, etc.);
- Indirect energy, CO_2 – emissions related to the construction of the animal production buildings and equipment;
- Postfarm, CO_2 – emissions related to the processing and transportation of livestock product between the production and retail point.

FIGURE 6. Global livestock production and GHG emissions from livestock, by commodity and regions



Source: GLEAM.

3.4 EMISSIONS BY REGIONS

Regional emissions and production profiles vary widely (Figure 6). Differences are explained by the respective shares of ruminants or monogastrics in total livestock production, and by differences in emission intensities for each product, between regions.

Latin America and the Caribbean have the highest level of emissions (almost 1.3 gigatonnes CO_2-eq), driven by an important production of specialized beef. Although at reduced pace in recent years, ongoing land-use change contributes to high CO_2 emissions in the region, due to the expansion of both pasture and cropland for feed production.

With the highest livestock production and relatively high emission intensities for its beef and pork, East Asia has the second highest level of emissions (more than 1 gigatonnes CO_2-eq).

North America and Western Europe have similar GHG emission totals (over 0.6 gigatonnes CO_2-eq) and also fairly similar levels of protein output. However, emission patterns are different. In North America, almost two-thirds of emissions originate from beef production which has high emission intensities. In contrast, beef in Western Europe mainly comes from dairy herds with much lower emission intensities (Section 4). In North America, emission intensities for chicken, pork and milk are lower than in Western Europe because the region generally relies on feed with lower emission intensity.

South Asia's total sector emissions are at the same level as North America and Western Europe but its protein production is half what is produced in those areas. Ruminants contribute a large share due to their high emission intensity. For the same reason, emissions in sub-Saharan Africa are large, despite a low protein output.

KEY MESSAGES OF CHAPTER 4

- Enteric fermentation and feed production are the main emission sources for ruminants.

- Beef produced by dairy cattle has generally lower emission intensity than beef produced by specialised beef cattle. This is explained by the fact that emissions from reproductive animals are allocated to milk and meat in the case of the dairy herd, and to meat only in the case of the beef herd.

- Beef and milk production have higher emission intensities in systems characterized by low productivity. This is due to low feed digestibility, less efficient herd management practices and low reproduction performance. This relationship between emission intensity and productivity is not clearly observed for monogastric species, as highly productive systems rely on high emission intensity feed.

- In Latin America and the Caribbean, one-third of the emissions from beef production are related to pasture expansion into forested areas.

- In pork and poultry supply chains, emissions mainly derive from feed production explained by the use of high emission intensity feed. For pork and chicken egg production, manure storage and processing are also an important source of emissions.

- Emissions related to energy consumption account for as much as 40 percent of emissions in pork and poultry supply chains.

- In pork production, lowest emission intensities are in backyard systems which rely on feed with low emissions, and among industrial systems which are most efficient at converting feed into animal products.

- Chicken meat and eggs have low emission intensities compared with other livestock products.

- For livestock production systems, N_2O, CH_4 and CO_2 emissions are losses of N, energy and organic matter that undermine the efficiency and productivity of production units.

EMISSIONS BY SPECIES

This chapter presents a summary analysis of emissions by animal species. A complete and detailed analysis including a detailed sensitivity analysis and a comparison of results with other studies is available in FAO (2013a and 2013b).

4.1 CATTLE

GHG emissions from cattle represent about 65 percent of the livestock sector emissions (4.6 gigatonnes CO_2-eq), making cattle the largest contributor to total sector emissions. Beef production contributes 2.9 gigatonnes or 41 percent of total sector emissions while emissions from milk production amount to 1.4 gigatonnes or 20 percent of total sector emissions.[11] Emissions allocated to other goods and services such as animal draught power and manure used as fuel represent 0.3 gigatonnes (Figure 10). These goods and services supplied by livestock are particularly important in South Asia and sub-Saharan Africa, where they account for almost 25 percent of emissions.

Average emission intensities are 2.8 kg CO_2-eq per kg of fat and protein corrected milk[12] for milk and 46.2 kg CO_2-eq per kg of carcass weight for beef.

Main emission sources: enteric fermentation and feed fertilization

Enteric fermentation is the main source of emissions from cattle. Related emissions amount to 1.1 gigatonnes, representing 46 percent and 43 percent of the total emissions in dairy and beef supply chains, respectively (Figures 7, 8, 9 and 10).

Feed emissions, including emissions from pasture management, form the second largest category of emissions, contributing about 36 percent to milk and beef emissions. Nitrous oxide emissions dominate, mostly originating from feed fertilization. When emissions from pasture expansion are added, feed emissions represent more than half of the emissions in specialized beef systems; dairy systems are generally not associated with pasture expansion.

Carbon dioxide emissions from energy use in feed supply chains represent about 10 percent of overall emissions. Emissions from energy consumption on farms and in processing are negligible in beef and limited in dairy (about 8 percent of emissions).

Higher emission intensity of the specialized beef herd

There is a distinct difference in emission intensity between beef produced from dairy herds and from specialized beef herds: the emission intensity

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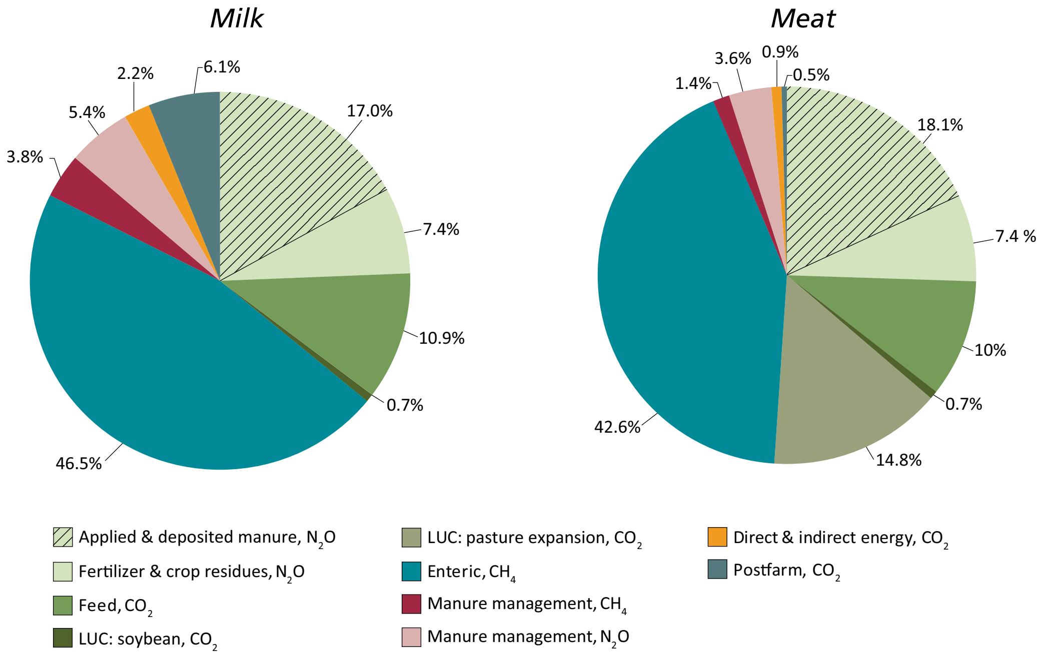
[11] Unless otherwise stated, the term "beef" refers to meat from both dairy and specialized beef herds.

[12] Milk is normalized in fat and protein corrected milk, to account for the heterogeneity in milk production.

FIGURE 7. Global emissions from cattle milk and beef supply chains, by category of emissions



Source: GLEAM.

TABLE 5. Global production, emissions and emission intensity for cattle milk and beef

Herd	**System**	**Production** *(Million tonnes)*		**Emissions** *(Million tonnes CO_2-eq)*		**Emission intensity** *(kg CO_2-eq/kg product)*	
		Milk[1]	**Meat**[2]	**Milk**	**Meat**	**Milk**[1]	**Meat**[2]
Dairy	Grazing	77.6	4.8	227.2	104.3	2.9[3]	21.9[3]
	Mixed	430.9	22.0	1 104.3	381.9	2.6[3]	17.4[3]
	Total dairy	**508.6**	**26.8**	**1 331.1**	**486.2**	**2.6[3]**	**18.2[3]**
Specialized beef	Grazing		8.6		875.4		102.2[3]
	Mixed		26.0		1 462.8		56.2[3]
	Total beef		**34.6**		**2 338.4**		**67.6 [3]**
Post-harvest emissions[4]				87.6	12.4		
Totals		**508.6**	**61.4**	**1 419.1**	**2 836.8**	**2.8[5]**	**46.2[5]**

[1] Product: FPCM.

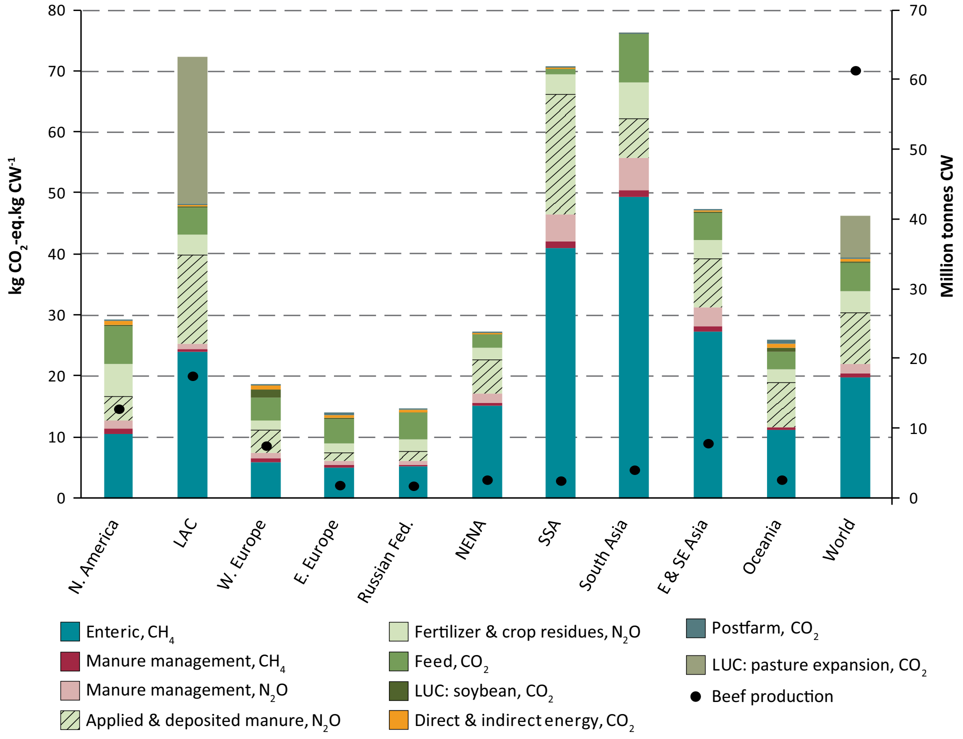
[2] Product: carcass weight (CW).

[3] Does not include post-harvest emissions.

[4] Computed at commodity and country level.

[5] Includes post-harvest emissions.

FIGURE 8. Regional variation in beef production and GHG emission intensities



Source: GLEAM.

of beef from specialized beef herds is almost fourfold that produced from dairy herds (68 vs. 18 kg CO_2-eq per kg of carcass weight) (Table 5).

This difference is primarily due to the fact that dairy herds produce both milk and meat while, on the other hand, specialized beef herds mostly produce beef. As a consequence, emissions from dairy herds are attributed to milk and meat while emissions from beef herds are allocated to meat (in both cases, a limited fraction is allocated to other goods and services, such as draught power, and manure used as fuel).

A closer look at emission structure shows that emissions from reproductive animals (the "breeding overhead") exclusively explain the difference: when only fattening animals are considered, specialized beef and surplus dairy calves have similar emission intensity per kg of carcass weight. In addition, the breeding cohorts represent 69 percent of the herd in specialized beef herds, compared with 52 percent in dairy systems.

Because of differences in feed quality and herd management, grazing systems generally have higher emission intensities than mixed systems.[13] Average emission intensities are particularly high for specialized beef raised in grazing systems in Latin America and the Caribbean, due to the land-use change emissions related to pasture expansion. The difference in emission intensities between grazing and mixed systems is less pronounced for beef from dairy herds and negligible for milk.

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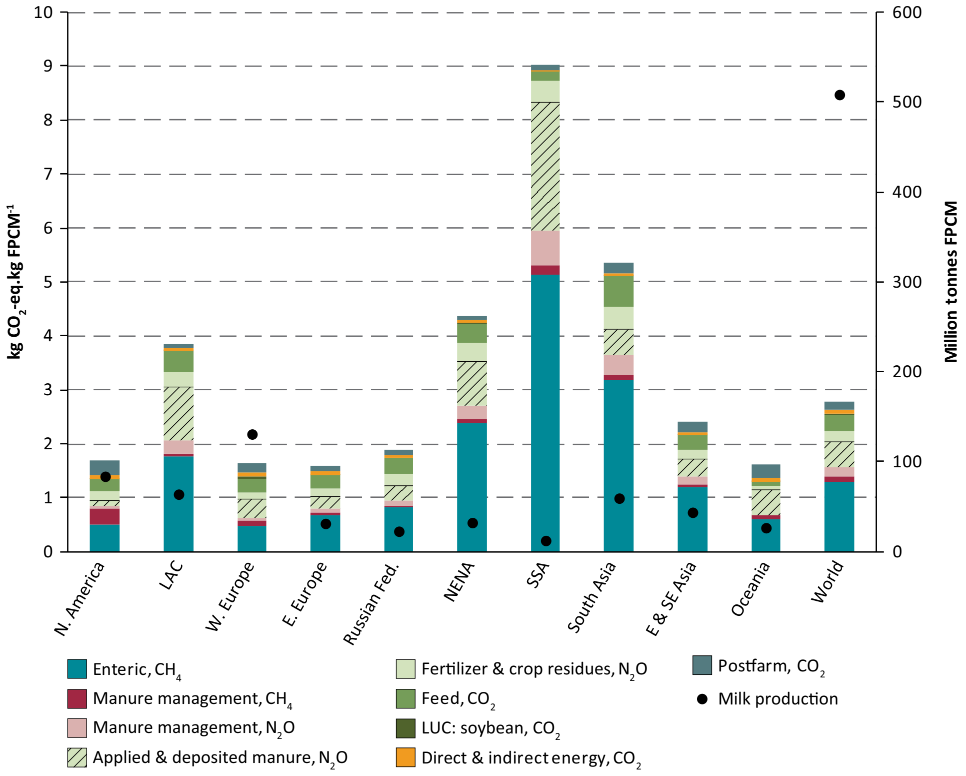
[13] Mixed and grazing systems are defined on the basis of animal diet and mix of products in farm output (Chapter 2).

FIGURE 9. Regional variation in cattle milk production and GHG emission intensities



Source: GLEAM.

Higher emission intensities in low productivity systems

Beef production

Emission intensities for beef are highest in South Asia, sub-Saharan Africa, Latin America and the Caribbean, and East and Southeast Asia (Figure 8). Higher emissions are largely caused by low feed digestibility (leading to higher enteric and manure emissions), poorer animal husbandry and lower slaughter weights (slow growth rates leading to more emissions per kg of meat produced) and higher age at slaughter (longer life leading to more emissions).

In Latin America and the Caribbean, one-third of the emissions (24 kg CO_2-eq/kg carcass weight) from beef production is estimated to come from pasture expansion into forested areas. This estimate is to be taken with caution, given the numerous methodological and data uncertainties affecting land-use change emissions estimates (Chapter 2) (FAO, 2013a and 2013b).

In Europe, about 80 percent of the beef is produced from dairy animals (surplus calves and culled cows), resulting in lower emission intensities, as explained above.

Milk production

Generally, the emission intensity of milk production is lowest in industrialized regions of the world (below 1.7 kg CO_2-eq/kg milk, compared with regional averages going as high as 9 kg CO_2-eq/kg milk). Better animal feeding and nutrition

TABLE 6. Global production, emissions and emission intensity for buffalo milk and meat

System	Production (Million tonnes)		Emissions (Million tonnes CO_2-eq)		Emission intensity (kg CO_2-eq/kg product)	
	Milk[1]	Meat[2]	Milk	Meat	Milk[1]	Meat[2]
Grazing	2.7	0.1	9.0	4.7	3.4[3]	36.8[3]
Mixed	112.6	3.2	357.9	175.2	3.2[3]	54.8[3]
Post-harvest emissions[4]			23.0	0.3		
Totals	**115.2**	**3.4**	**389.9**	**180.2**	**3.4[5]**	**53.4[5]**

[1] Product: FPCM.

[2] Product: CW.

[3] Does not include postfarm emissions.

[4] Computed at commodity and country level.

[5] Includes postfarm emissions.

reduce CH_4 and manure emissions (lower release of N and volatile solids). Higher milk yields imply a shift of the cow's metabolism in favour of milk and reproduction as opposed to body maintenance, contributing to lower emission intensities.

In low productivity regions, enteric fermentation is the main emission source. In industrialized regions, feed production and processing, and manure together are as important a source of emissions as enteric fermentation.

Manure management emissions are relatively high in North America where, on average, 27 percent of manure from the dairy sector is managed in liquid systems that produce greater quantities of CH_4 emissions.

4.2 BUFFALO

Total GHG emissions from buffalo production (meat, milk and other products and services) represent 9 percent of the sector's emissions. They amount to 618 million tonnes CO_2-eq, of which 390 million tonnes come from milk production, 180 million tonnes from meat production and 48 million tonnes CO_2-eq from other goods and services, such as manure used as fuel and draught power (Table 6).

Main emission sources: enteric fermentation and feed fertilization

Over 60 percent of emissions from buffalo meat and milk production come from enteric fermentation, compared with 45 percent for cattle. The difference is due to the generally lower digestibility of feed rations (Figure 11).

The fertilization of feed crops is the second largest emission source, representing 17 percent for milk production and 21 percent for meat production.

Emissions originating from land-use change are close to nil, given the absence of buffalo in areas where pasture is expanding as well as the limited presence of soybean products in the ration.

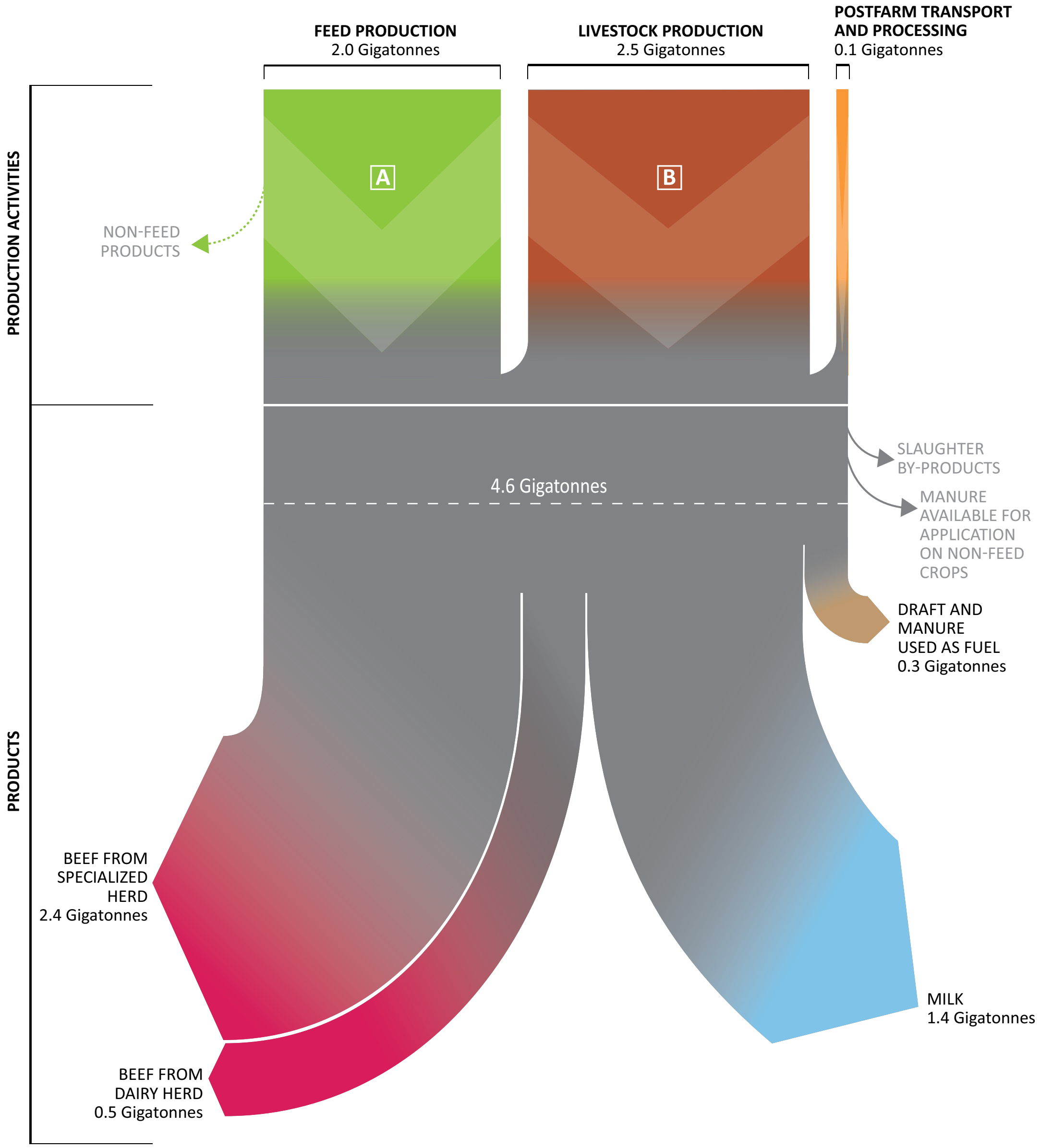
Geographically-concentrated production

Buffalo production is geographically concentrated in South Asia, Near East and North Africa and East and Southeast Asia, with South Asia alone producing as much as 90 percent and 70 percent of the global buffalo milk and meat, respectively. East and Southeast Asia produce 20 percent of buffalo meat; the other regions making limited contributions to meat and milk outputs (Figure 12 and 13).

Milk production

About 80 percent of buffalo milk is produced in mixed systems located in semi-arid climates. Average milk emission intensity ranges from 3.2 in South Asia to 4.8 kg CO_2-eq/kg FPCM in East and Southeast Asia. Milk produced in South Asia has the lowest emission intensity, explained by higher yields.

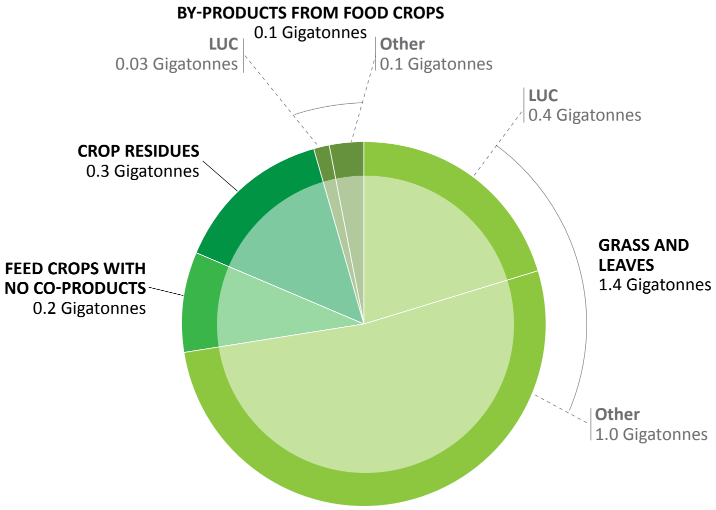
FIGURE 10. Global flows of emissions in cattle supply chains



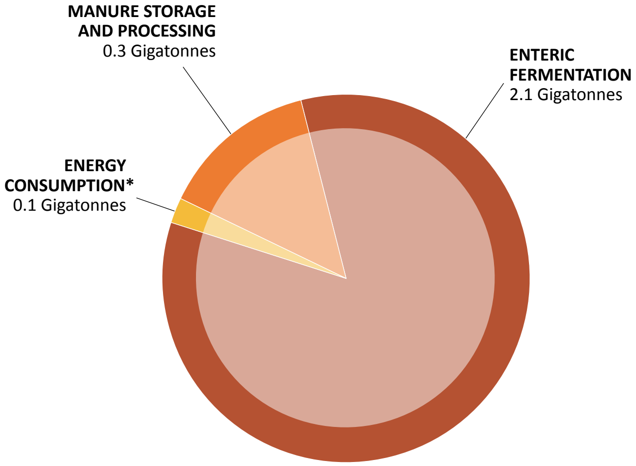
GHG EMISSIONS FROM GLOBAL LIVESTOCK SUPPLY CHAINS, BY PRODUCTION ACTIVITIES AND PRODUCTS

Different types of feed crops are identified: second grade crops (food crops that do not match quality standards for human consumption and that are fed to livestock), feed crops with no co-products (crops cultivated as feed, e.g. maize, barley), crop residues (residues from food of feed crops, e.g. maize, stover, straw), and by-products from food crops (by-products from food production and processing, e.g. soybean cakes, bran). The arrow "non-feed products" reminds us that the emissions from the production of feed are shared with other sectors. For example, household food wastes used to feed pigs in backyard systems are estimated to have an emission intensity of zero because emissions are entirely attributed to household food. In the same way, emissions related to crop residues (e.g. maize stover) are low because most of the emissions are attributed to the main product (maize grain).

No emissions could be allocated to slaughterhouse by-products (e.g. offal, skins, blood). Case studies show that by-products can add about 5 to 10 percent to the total revenue at slaughterhouse gate; for example, for beef and pork in OECD countries (FAO, 2013a and 2013b).



A FEED PRODUCTION

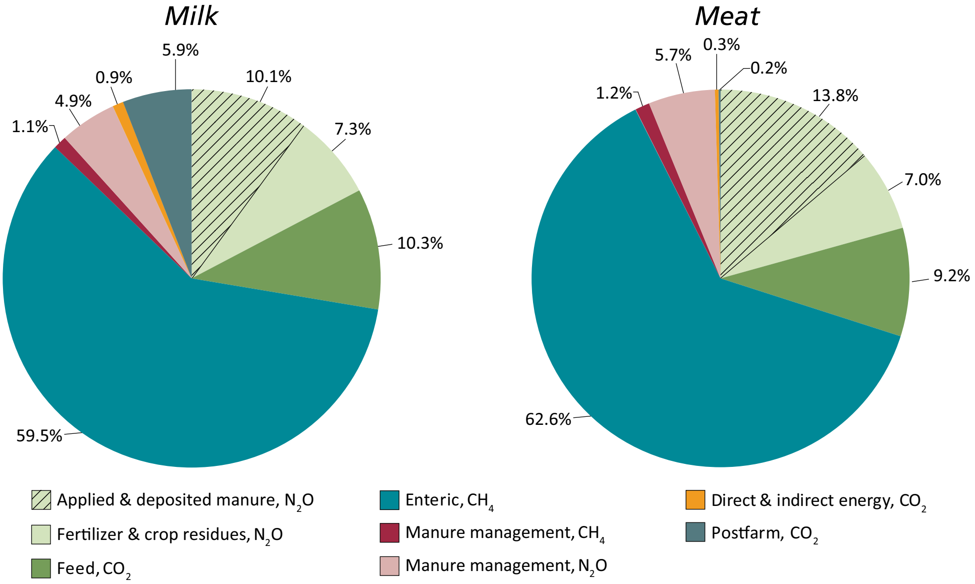


B LIVESTOCK PRODUCTION

*Embedded energy related to the manufacture of on-farm buildings and equipment is included in this category.

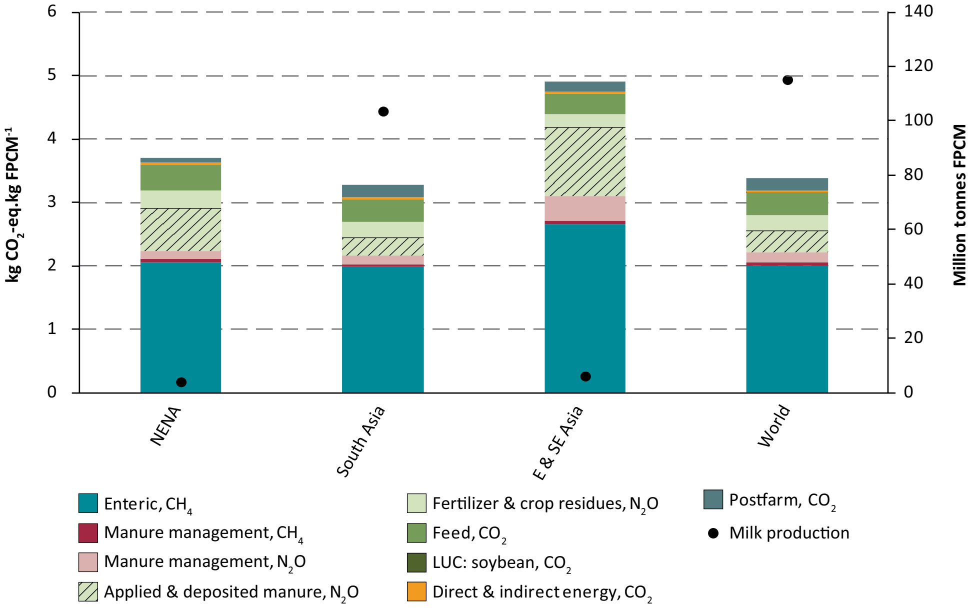
Source: GLEAM.

FIGURE 11. Global emissions from buffalo milk and meat supply chains, by category of emissions



Source: GLEAM.

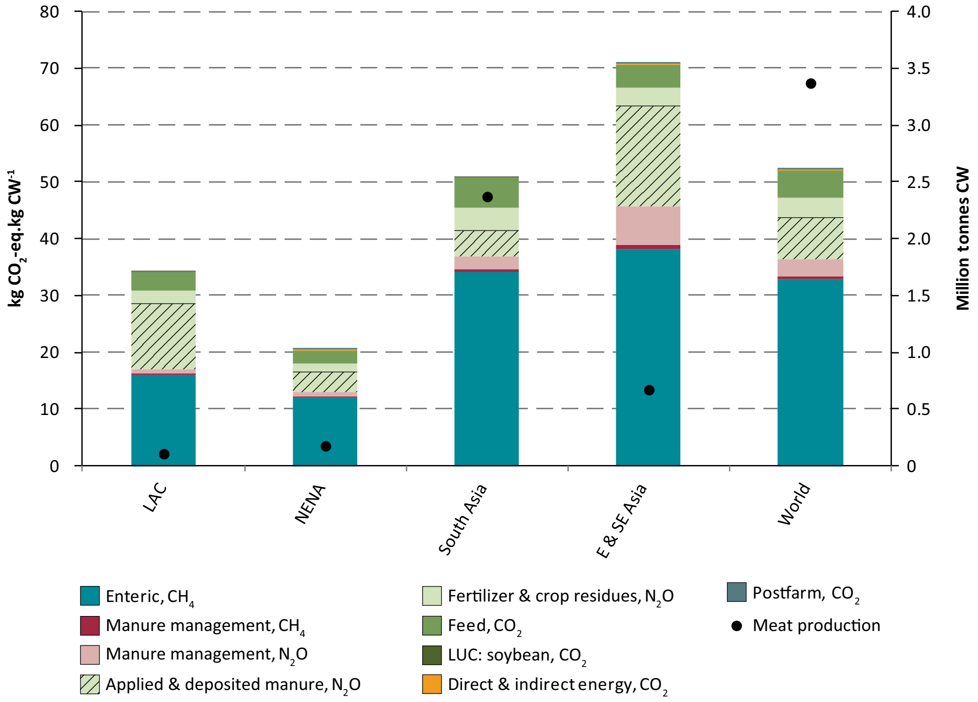
FIGURE 12. Regional variation in buffalo milk production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

FIGURE 13. Regional variation in buffalo meat production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

Meat production

Seventy percent of all buffalo meat originates from both grazing and mixed systems in the arid zones, which also have the lowest emission intensities.

Emission intensity of buffalo meat production at regional level ranges from 21 kg CO_2-eq/kg CW in NENA to 70.2 kg CO_2-eq/kg CW in East and Southeast Asia. Emission intensity of buffalo meat production is particularly high in East and Southeast Asia because productivity of the animals is low due to poor feed resources and low reproductive efficiency.

4.3 SMALL RUMINANTS (SHEEP AND GOATS)

Representing about 6.5 percent of the sector's global emissions, emissions from small ruminants amount to 475 million tonnes CO_2-eq , of which 299 million tonnes are allocated to meat production, 130 million tonnes to milk production and 46 million tonnes CO_2-eq to other goods and services.

Goat milk has a lower milk emission intensity compared with sheep (Table 7), due to higher yields.[14] Average emission intensity for small ruminant meat is 23.8 kg CO_2-eq/kg CW, with no large differences between sheep and goat meat.

Main emission sources: enteric fermentation and feed fertilization

Similar to buffalo, over 55 percent of emissions from small ruminant meat and milk production come from enteric fermentation (Figure 14). Slightly more than 35 percent of emissions are from feed production. Compared with buffalo

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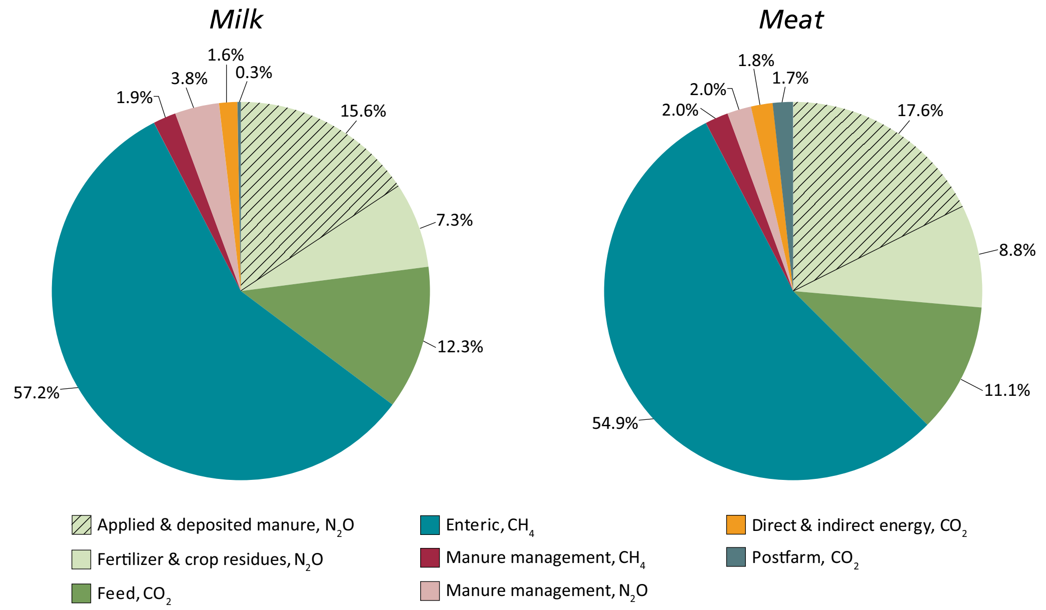
[14] Fat and protein corrected milk.

FIGURE 14. Global emissions from small ruminant milk and meat supply chains, by category of emissions



Source: GLEAM.

TABLE 7. Global production, emissions and emission intensity for small ruminants

Species	System	Production *(Million tonnes)*		Emissions *(Million tonnes CO_2-eq)*		Emission intensity *(kg CO_2-eq/kg product)*	
		Milk[1]	**Meat**[2]	**Milk**	**Meat**	**Milk**[1]	**Meat**[2]
Sheep	Grazing	3.1	2.8	29.9	67.3	9.8[3]	23.8[3]
	Mixed	5.0	4.9	37.1	115.0	7.5[3]	23.2[3]
	Total sheep	**8.0**	**7.8**	**67.1**	**182.4**	**8.4**[3]	**23.4**[3]
Post-harvest emissions[4]				0.3	4.1		
Goats	Grazing	2.9	1.1	17.7	27.2	6.1[3]	24.2[3]
	Mixed	9.0	3.7	44.3	84.5	4.9[3]	23.1[3]
	Total goats	**11.9**	**4.8**	**62.0**	**111.7**	**5.2**[3]	**23.3** [3]
Post-harvest emissions[4]				0.4	1.0		
Totals		**20.0**	**12.6**	**129.8**	**299.2**	**6.5**[5]	**23.8**[5]

[1] Product: FPCM.

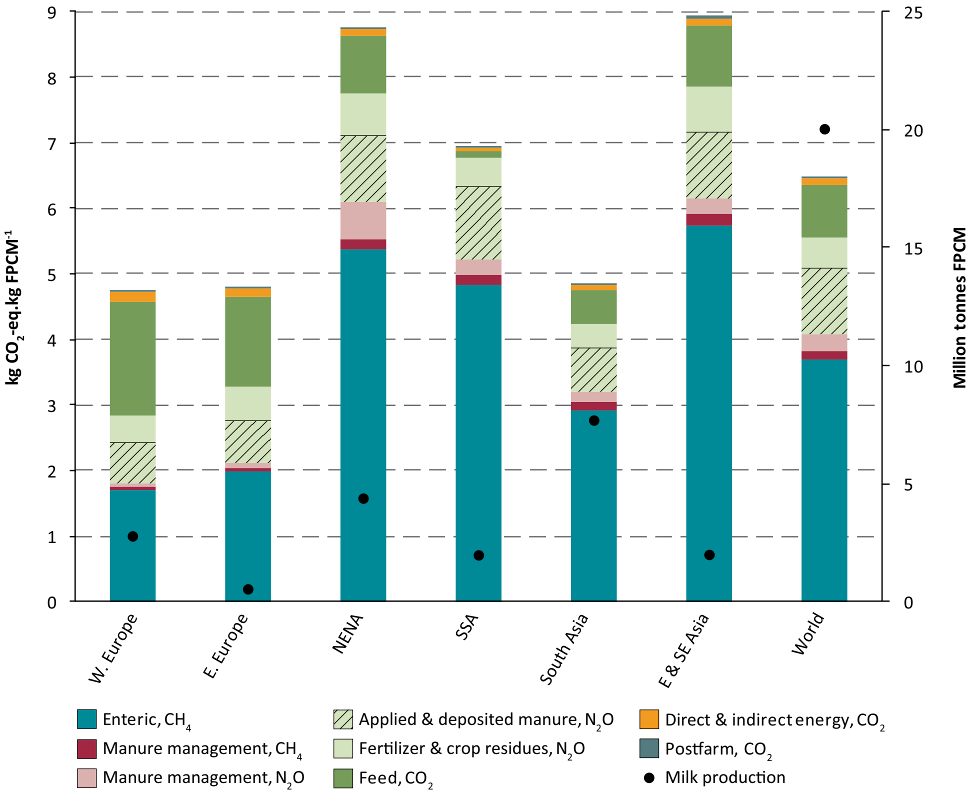
[2] Product: CW.

[3] Does not include post-harvest emissions.

[4] Computed at commodity and country level.

[5] Includes post-harvest emissions.

FIGURE 15. Regional variation in small ruminant milk production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

and cattle, post-harvest energy consumption is lower due to less processing. Manure emissions are also lower because manure is mainly deposited on pasture (Figure 15).

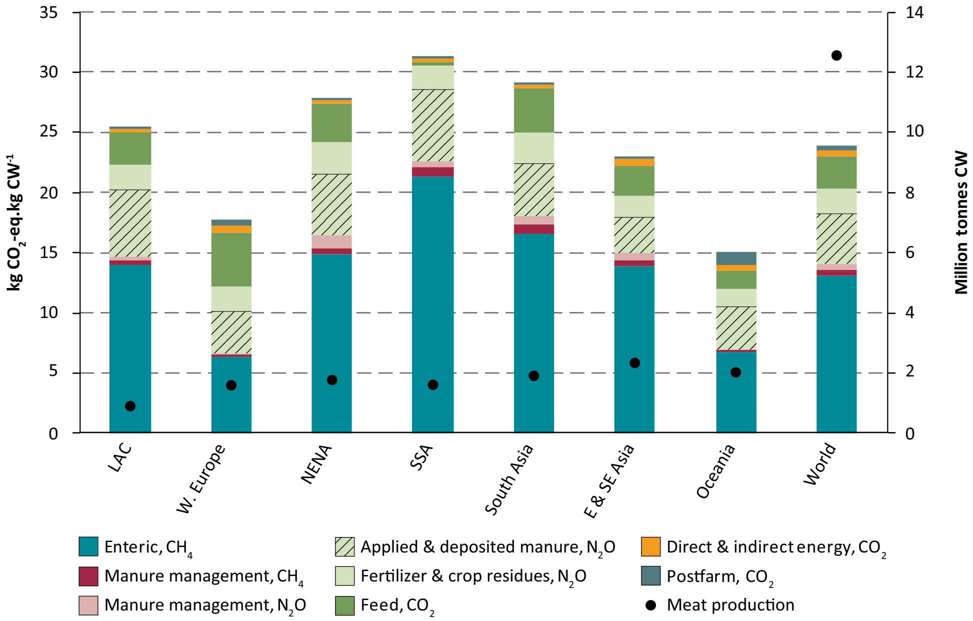
Production mainly in least affluent regions, with higher emission intensities

With the exception of milk in Western Europe and lamb and mutton meat in Oceania and Western Europe, small ruminant production is generally more important in less affluent regions (Figures 15 and 16).

Fibre production can represent a substantial part of emissions

Small ruminants not only produce edible products, but also important co-products including wool, cashmere and mohair. The relative economic value was used to partition emissions between edible products (meat and milk) and non-edible products (natural fibre). In regions where natural fibre production is important and has high economic value, a substantial share of emissions can be attributed to these products, reducing the share of emissions attributed to milk and meat production. Globally, 45 million tonnes CO_2-eq are allocated to fibre production (Figure 17).

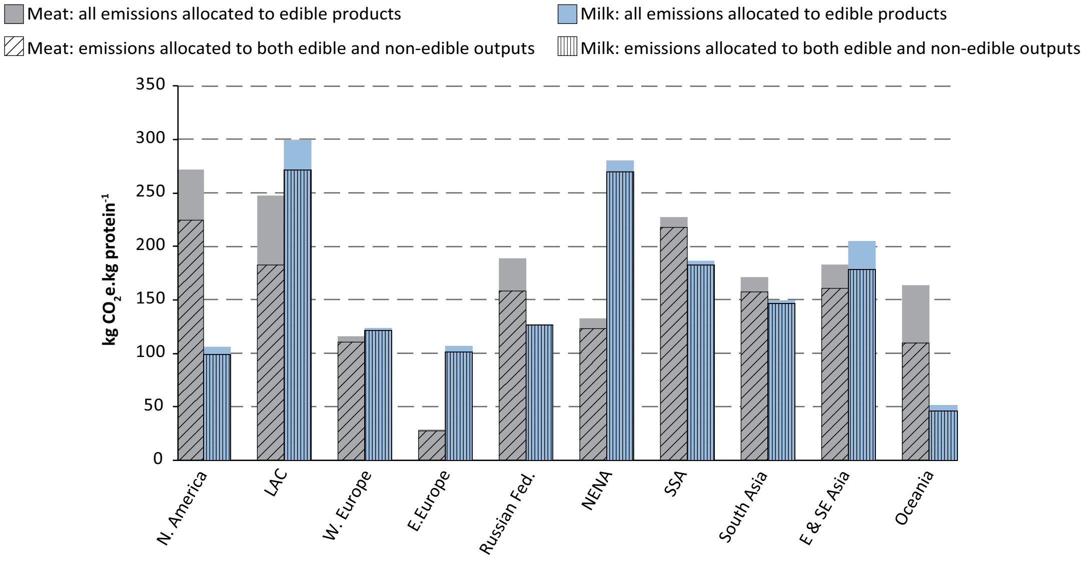
FIGURE 16. Regional variation in small ruminant meat production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

FIGURE 17. Emissions per kg meat and milk protein from small ruminants, with and without allocation of emissions to non-edible outputs



Source: GLEAM.

4.4 PIG

Globally, pork production is estimated to emit about 668 million tonnes CO_2-eq, representing 9 percent of the livestock sector emissions.

Main emission sources: feed production and manure

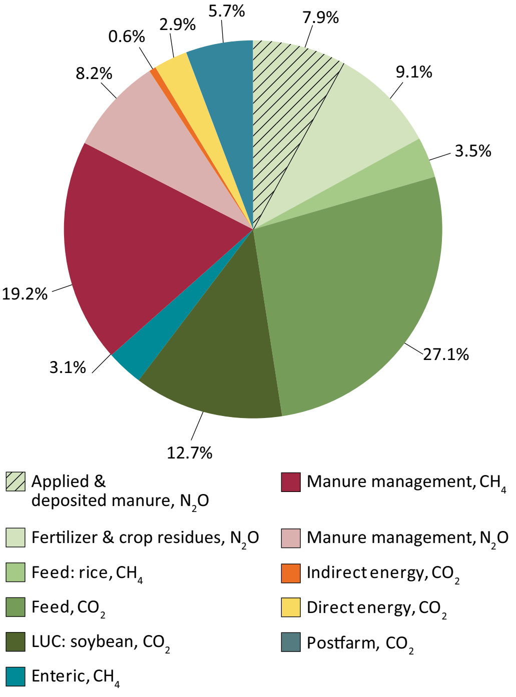
Feed production contributes to 48 percent of emissions. An additional 12.7 percent relate to land-use change caused by soybean expansion for feed production (Figure 18). About 27 percent of emissions are related to the production of fertilizers, the use of machinery and transport for feed production. About 17 percent of emissions are caused by fertilization (emitting N_2O) with both synthetic fertilizers and manure.

Manure storage and processing are the second largest source of emissions, representing 27.4 percent of emissions. Most manure emissions are in the form of CH_4 (19.2 percent, predominantly from anaerobic storage systems in warm climates); the rest is in the form of N_2O (8.2 percent).

Postfarm emissions from processing and transport contribute moderately to total GHG output (5.7 percent).

On-farm energy consumption represents only 3.5 percent of emissions; however, when other energy uses in postfarm activities and feed production are added, emissions from overall energy use amount to about one-third.

FIGURE 18. Global emissions from pig supply chains, by category of emissions



Source: GLEAM.

Lowest emission intensity in backyard systems

On a global scale, the difference in emission intensities between the various production systems is not substantial. Intermediate[15] systems have the highest average emission intensities, followed by industrial and backyard. Industrial systems do, however, account for the majority of both total production and emissions (Table 8).

Backyard systems have relatively high manure emissions, caused by larger amounts of volatile

TABLE 8. Global production, emissions and emission intensity for pigs

System	Production *(Million tonnes CW)*	Emissions *(Million tonnes CO_2-eq)*	Emission intensity *(kg CO_2-eq/kg CW)*
Backyard	22.9	127.5	5.6
Intermediate	20.5	133.9	6.5
Industrial	66.8	406.6	6.1
Totals	**110.2**	**667.9**	**6.1**

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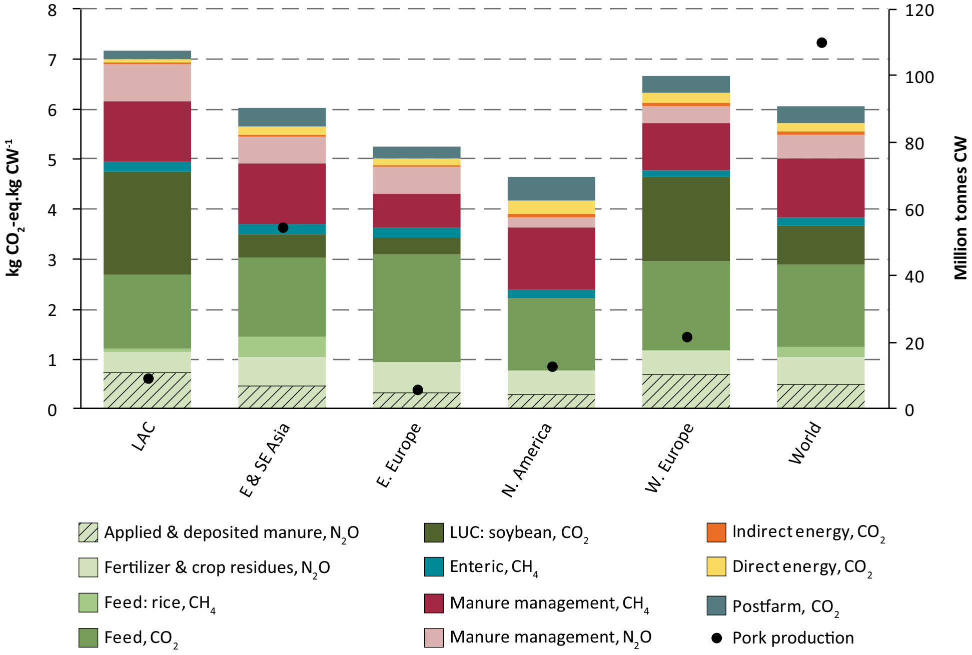
[15] Farming systems defined on the basis of the animal ration and level of market integration – see Chapter 2.

FIGURE 19. Regional variation in pork production and GHG emission intensities*



* Regions accounting for less than 1 percent of world production are omitted.

Source: GLEAM.

solids (VS) and N excretion per kg of meat produced. This is caused by poor conversion[16] of low quality feed. Higher manure emissions in backyard systems are, however, offset by relatively low feed emissions, as the provision of low quality feed has low emissions.

Emission intensity in intermediate systems is generally higher than that in industrial systems. This is explained by a poorer feed conversion and a higher share of rice products in animal rations. A large share of intermediate production is located in rice-growing areas and uses rice by-products as feed material (East and Southeast Asia); the production of paddy rice emits CH_4 and has higher emission intensities than the production of other cereal products. Higher emission intensities are also linked to the storage of manure in anaerobic storage systems, leading to higher CH_4 emissions.

Feed emission intensity: driver of regional differences

Mainly due to cultural preferences, the global pig population is geographically concentrated. Ninety-five percent of production takes place in three regions: East Asia, Europe and the Americas (Figure 19). This geographical concentration close to consumption areas has been maintained over time by importing increasingly large amounts of feed.

Emission intensities in the top-five producing regions range between 4.6 and 7.1 kg CO_2-eq per kg CW.

Regional differences are mostly explained by variation in feed material in the ration, animal

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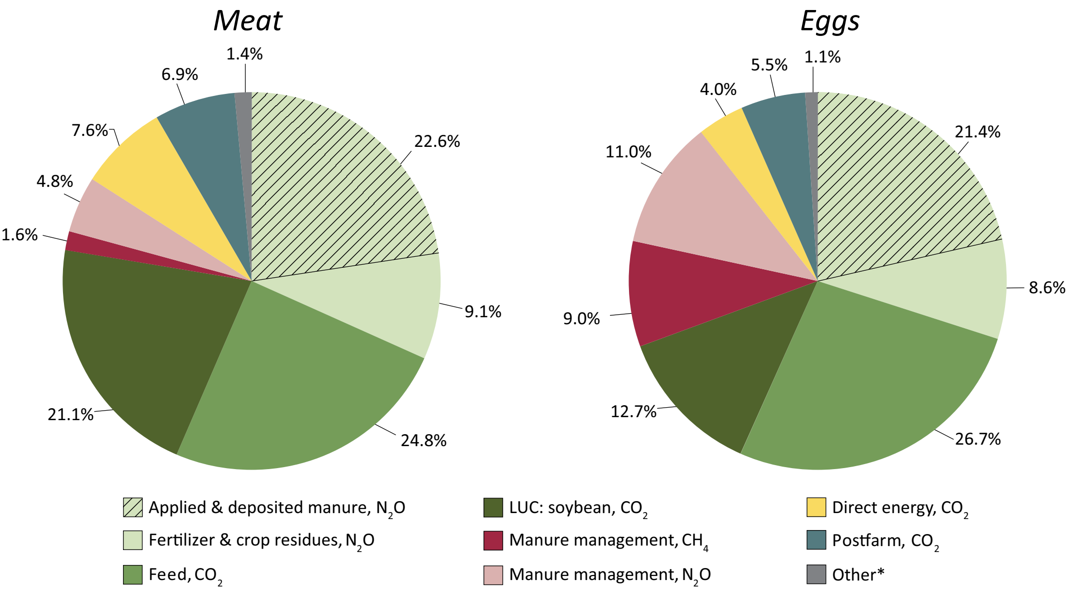
[16] The feed conversion ratio is kg of feed used per kg of meat produced. Feed conversion ratio is an indicator of feed-use efficiency and is mostly determined by feed quality, animal genetics, animal health and animal husbandry practices.

FIGURE 20. Global emissions from chicken meat and egg supply chains, by category of emissions



* Includes "Feed: rice, CH_4" and "Indirect energy, CO_2".

Source: GLEAM.

productivity and climate. In East and Southeast Asia, emissions from manure are comparatively more important, mainly due to the types of manure storage systems and climatic conditions. In Europe and Latin America and the Caribbean, high emission intensities are partly explained by feeding of soybean cake originating from areas where land-use change has occurred in the past 20 years.

4.5 CHICKEN

Globally, chicken supply chains emit GHG emissions of 606 million tonnes CO_2-eq, representing 8 percent of the sector's emissions.

Main emission source: feed production (fertilization, use of machinery and transport)

Feed production contributes about 57 percent of emissions from both chicken and egg supply chains, with an additional 21.1 percent related to the expansion of soybean cultivation in the case of meat and 12.7 percent in the case of eggs (Figure 20). Broiler rations are richer in protein and, on average, include a higher share of soybean sourced from areas where land-use conversion has taken place.

Manure emissions account for 20 percent of emissions in eggs but only 6 percent in broilers. This is due to different management systems; most of the manure from specialized meat production is managed in dry, aerobic conditions whereas that from hens is often managed in liquid systems with long-term pit storage.

Emissions from energy consumption, including direct energy, feed CO_2 and postfarm CO_2 are 35 to about 40 percent of total emissions.

Lower emission intensity for industrial systems

Three types of chicken production systems exist: backyard layers and industrial layers, producing both meat and eggs, and industrial broilers, producing only meat.[17]

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[17] Farming systems defined on the basis of the animal ration and level of market integration (Chapter 2).

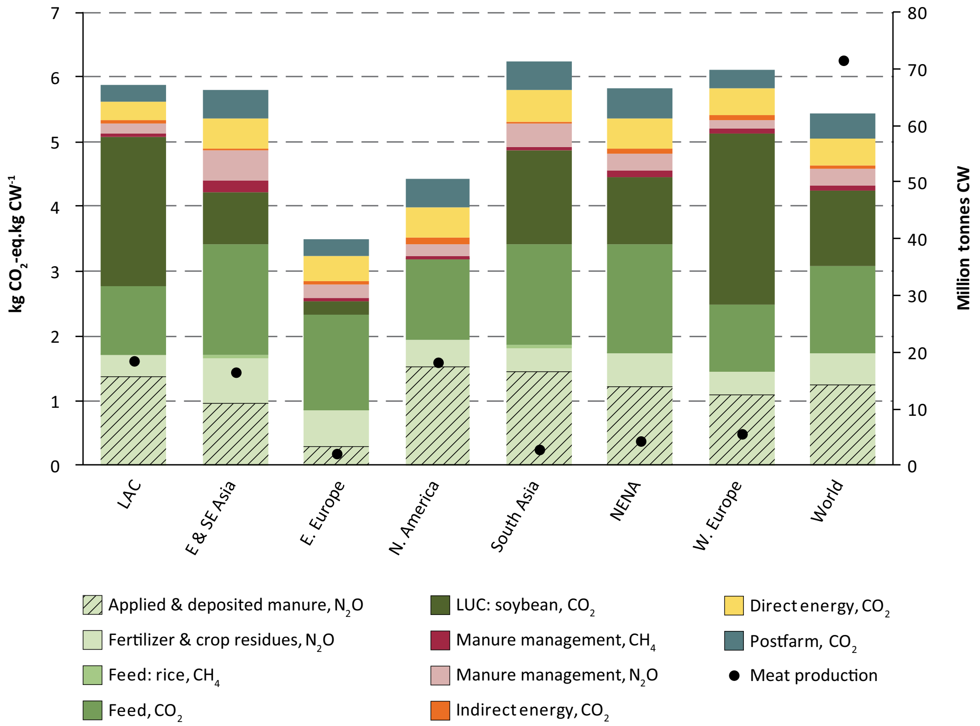
Making up over 90 percent of meat production, industrial broilers have the lowest emission intensity (Table 9). Likewise, the production of eggs from intensively-managed laying hens represents over 85 percent of output and has a lower emission intensity than the production of eggs from backyard systems. Backyard systems have higher emission intensities but they represent less than 10 percent of GHG emissions. Backyard production occurs in small units, with slow growing animals

TABLE 9. Global production, emissions and emission intensity for chickens

System	Production (Million tonnes)		Emissions (Million tonnes CO_2-eq)		Emission intensity (kg CO_2-eq/kg product)	
	Eggs	Meat[1]	Eggs	Meat	Eggs	Meat[1]
Backyard	8.3	2.7	35.0	17.5	4.2	6.6
Layers	49.7	4.1	182.1	28.2	3.7	6.9
Broilers		64.8		343.3		5.3
Totals	**58.0**	**71.6**	**217.0**	**389.0**	**3.7**	**5.4**

[1] Product: CW.

FIGURE 21. Regional variation in chicken meat production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

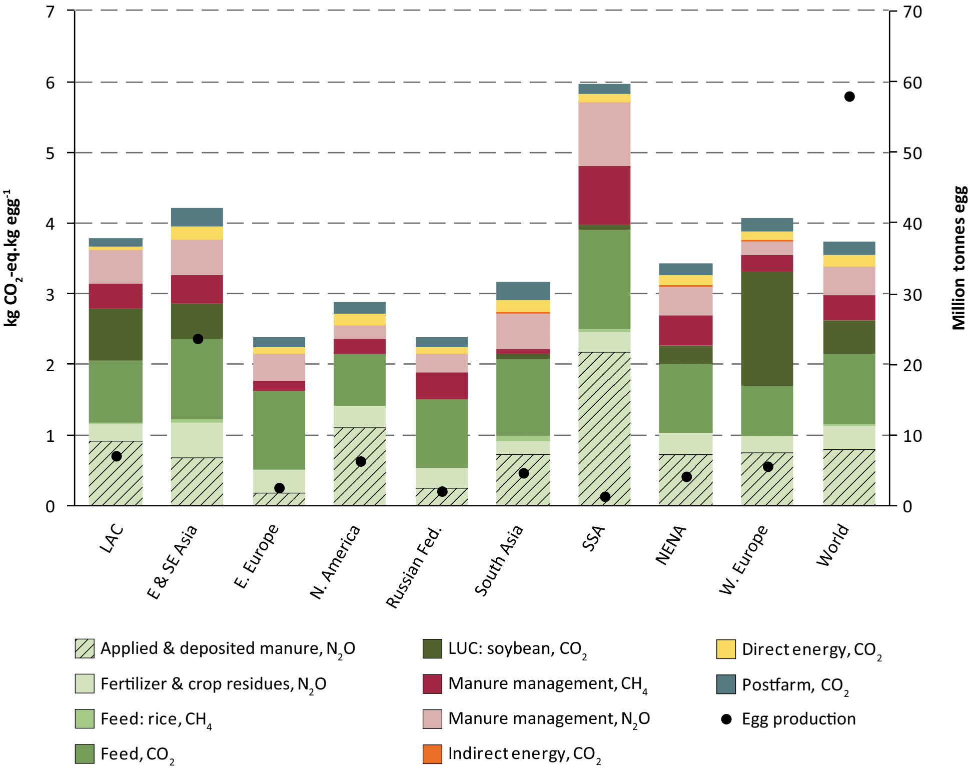
and lower egg production per hen than industrial systems.

Several factors explain the higher emission intensities of backyard systems. First, hens in backyard systems have poor feed conversion ratios because of the relatively low quality of feed and because birds spend energy scavenging for feed. Second, backyard systems have a higher proportion of unproductive animals (around 10 percent of the backyard flock, compared with 4 percent of the broiler flock and 1 percent of the layer flock). This is due to much higher death rates (largely through disease and predation) and lower fertility rates. In backyard systems, manure N_2O emission intensity is also higher due to poor feed conversion (higher rates of transformation of feed N into N_2O emissions).

Similar emission intensities in top three producing regions

Latin America and the Caribbean, North America and East and Southeast Asia dominate chicken meat production, and the latter region also dominates egg production (Figures 21 and 22). Average emission intensities are at similar levels in the top three production regions, reflecting the relative standardization of production systems and similar levels of technology. However, North American

FIGURE 22. Regional variation in chicken egg production and GHG emission intensities*



* Regions accounting for less than 2 percent of world production are omitted.

Source: GLEAM.

systems generally have slightly lower emission intensities, as a result of good feed conversion and low emission intensity feed (about 1 kg CO_2-eq per kg feed dry matter). Higher emission intensity feed, related to sourcing feed from areas of deforestation, cause emission intensities to be higher in Western Europe and Latin America and the Caribbean. In East and Southeast Asia, poorer feed conversion ratios and more anaerobic storage of manure explain the higher emissions compared with North America.

4.6 CROSS-CUTTING OBSERVATIONS

GHG emissions and natural resource use efficiency

To the climatologist, CH_4, N_2O and CO_2 are GHGs released into the atmosphere. However, for the livestock producer, these emissions are losses of energy, nutrients and soil organic matter. Their emissions often reflect the non-efficient use of initial inputs and resources. These losses undermine the efficiency, and often the economic viability, of supply chains.

Methane

Enteric CH_4 emissions mean a loss of energy to the production system: part of the energy ingested as feed is lost in the form of CH_4 instead of being assimilated by animals and used for production. Livestock producers make substantial efforts to produce feed or bring animals to pastures; feed is typically the main production cost item in mixed and intensive systems. Wasting part of the feed energy in the form of CH_4 is, thus, not only a climate change issue but also damages production. Furthermore, feed production mobilizes natural resources, such as water, land, fossil fuels and rock phosphorus; its wastage is also detrimental to other dimensions of environmental sustainability.

Likewise, CH_4 emissions from manure are another form of energy loss that can be recovered when manure is fed into a biogas digester.

The total enteric CH_4 emissions of the sector are 2.7 gigatonnes CO_2-eq per year, or 144 million tonnes of oil equivalent per year - about the energy use of South Africa (World Bank, 2013). The total manure CH_4 emissions are 300 million tonnes CO_2-eq per year, or 16 million tonnes of oil equivalent per year - about the energy use of Ireland.

While manure CH_4 emissions could be largely recovered, enteric CH_4 losses can only be partially avoided given current knowledge. These figures nevertheless give an impression of the magnitude of the loss. This has not escaped producers and improving the energy efficiency of feed is now the main argument for the use of dietary lipids, with reduction of enteric emissions being seen as a co-benefit.

Nitrous oxide

Nitrous oxide emissions, either direct or indirect from NH_3 losses, are both forms of N loss. Nitrogen is a macronutrient of plants, key to improving yield. Supplying reactive N to plants (in the form of manure or synthetic fertilizers) and preserving N in soils through agronomic practices come at significant cost to producers. They also involve high levels of fossil fuel consumption.

Nitrous oxide emissions from manure storage and processing, and from the application of manure on crops and pasture, represent about 3 million tonnes of N. This is about 15 percent of the mineral N fertilizer use that can be ascribed to feed (crop and pasture) production for the livestock sector (FAO, 2006).

Additional losses of N take place in the form of NH_3 and NO_x emissions into the atmosphere and leaching of soluble forms of N into ground water. While the latter is not quantified in this assessment, it is estimated that NH_3 and NO_x emissions represent significant N losses: NH_3 and NO_x emissions from the application of manure on crops and pasture, and from manure storage and processing are estimated to represent 26 million tonnes of N and 17 million tonnes of N, respectively. While not contributing to climate change, these emissions pose other environmental problems such as the acidification and eutrophication of natural habitats.

Carbon dioxide

Carbon dioxide emissions are related to fossil fuel consumption and land use activities.

On-site energy consumption is generally marginal in production cost structure but can be high in some cases, for example in intensive milk production systems. Energy-use efficiency can be improved by the adoption of better management practices (e.g. maintenance of equipment and operating time) and energy saving devices (e.g. heat pumps and thermal isolation), reducing both emissions and energy costs for farms and processing plants.

Soil organic matter, the primary form of carbon in soils, serves several functions. From an agricultural standpoint, it is important as a "revolving nutrient fund", as well as an agent to improve soil structure, maintain tilth and minimize erosion. (FAO, 2005). When soil organic matter is lost, either through inadequate agricultural practices in feed production or pasture degradation, the productivity of land decreases over time.

Important but poorly understood contribution of land use and land-use change

Land-use change is estimated to contribute 9.2 percent to the sector's overall GHG emissions (6 percent from pasture expansion, with the rest from feed crop expansion).

While relatively limited when averaged globally and over all species, land-use change emissions are significantly higher for some specific supply chains and regions. They amount to 15 percent for beef production (linked to pasture expansion) and 21 percent in chicken meat production (linked to soybean expansion). Because soybean is largely traded internationally, emissions from soybean expansion in Latin America and the Caribbean are actually attributed to production units around the world using soybean cakes imported from that region. This is different for pasture expansion, where induced emissions are entirely attributed to local production. As a result, land-use change emissions amount to 24 kg CO_2-eq per kg CW of beef in Latin America and the Caribbean, 33 percent of total emissions.

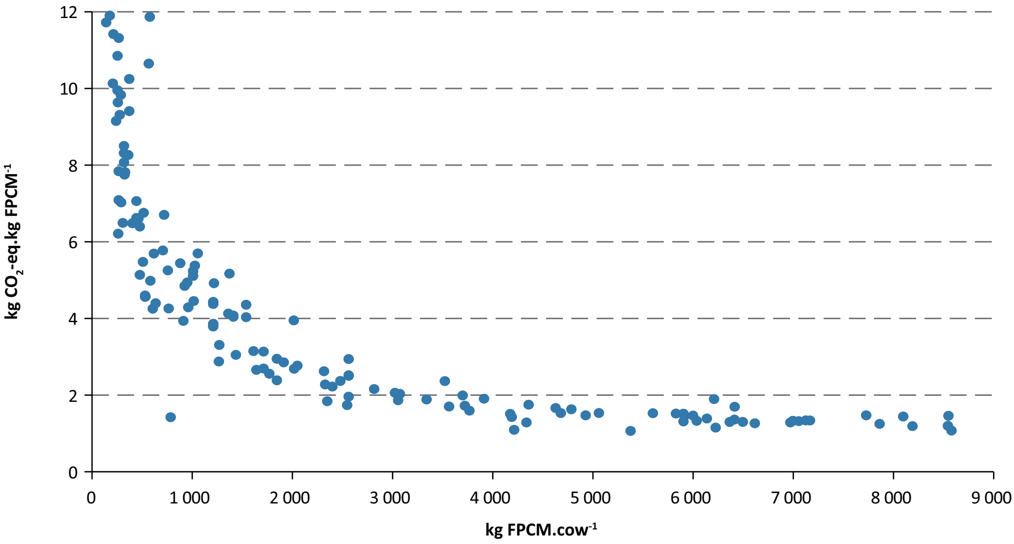
The drivers of land-use changes, and the attribution of the related emissions, as well as the methods available to compute land-use change emissions, are still highly debated.

As noted above, this report follows IPCC guidelines (IPCC, 2006) and three alternative approaches were tested in the context of a partial sensitivity analysis of the results. Land-use change emissions computed for Argentina ranged between 0.3 and 4.2 kg CO_2-eq per kg soybean cake and between 3.0 and 7.7 kg CO_2-eq per kg soybean cake produced in Brazil (the values resulting from the IPCC method and used in this assessment are 0.9 and 7.7 for Argentina and Brazil, respectively).

This analysis could not estimate changes in soil carbon stocks under constant land use management practices because of the lack of global databases and models. The effect of this simplification was, however, tested in the case of the European Union, where data are available (Soussana *et al.*, 2010). Permanent grasslands in the European Union represent a sink of 3.1 ± 18.8 million tonnes C per year (or 11.4 ± 69.0 million tonnes CO_2-eq per year), equivalent to 3 percent (± 18 percent) of the yearly emissions of the ruminant sector in the European Union. Net sequestration/emission of C in permanent pasture under stable management practices may thus be significant but the uncertainty about calculation parameters is such that it cannot be said with certainty whether permanent pastures are a net sink or source of emissions. The relative importance of land use emissions may even be higher in other parts of the world where permanent pastures are much more common and C sequestration higher (e.g. Africa, Latin America and the Caribbean).

Better understanding of soil organic carbon dynamics in grasslands and the development of methods and models to monitor and predict changes in C stocks are, however, required for the inclusion of this emission category in global assessments (FAO, 2013b).

FIGURE 23. Relationship between productivity and emission intensity of milk (country averages)



Source: Gerber *et al.*, 2011.

Correlation between productivity and emission intensities

Ruminants

In ruminant production, there is a strong relationship between productivity and emission intensity – up to a relatively high level of productivity, emission intensity decreases as yield increases.

Gerber *et al.* (2011) demonstrate this relationship for milk, illustrating how differences in productivity explain the variation in emission intensity between countries. Figure 23 highlights the strong correlation between output per cow and emission intensity per unit of product produced.

High-yielding animals producing more milk per lactation generally exhibit lower emission intensities for three main reasons. First, because emissions are spread over more units of milk, thus diluting emissions relative to the maintenance requirements of the animals. Second, because productivity gains are often achieved through improved practices and technologies which also contribute to emissions reduction, such as high quality feed and high performance animal genetics. And third, because productivity gains are generally achieved through herd management, animal health and husbandry practices that increase the proportion of resources utilized for productive purposes rather than simply being used to maintain the animals. This results in a reduced standing biomass (both in lactating and in replacement herds) per unit of milk produced. The impact per unit of milk is therefore reduced at both the individual cow and dairy herd level.

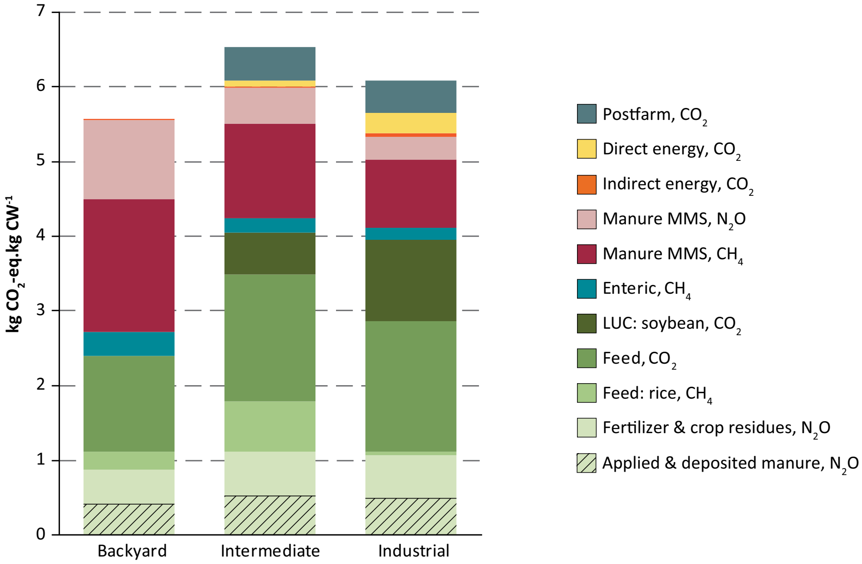
A large potential to mitigate emissions thus exists in low-yield ruminant production systems. Improved productivity at the animal and herd level can lead to a reduction of emission intensities while at the same time increasing milk output.

Monogastric species

The relation between productivity gains and emissions shows a different pattern for monogastric species.

In pig production, the relation between intensification and emission intensity follows a slight

FIGURE 24. Global emission intensity from pig supply chains, by main production systems



Source: GLEAM.

inverse U-shape relation (Figure 24). At the low end of the productivity spectrum, in backyard systems, emission intensity is low. The feed ration is mostly made up of wastes and by-products with low emission intensity which compensate for the high manure emissions per unit of product due to poor nutrient balancing and low digestibility. In contrast, industrial systems characterized by high productivity have slightly higher emission intensity on a global average than backyard systems. They have optimized feed conversion ratios but are penalized by the relatively high emission intensity of the feed materials they rely on (driven up by energy consumption and land-use change). Highest emission intensity is found among intermediate systems, which combine relatively high feed emission intensity with moderate feed conversion ratios. The diversity of manure emission intensities, not related to farming systems but rather to local manure management practices and climate, further blurs the relation between productivity and emission intensity.

The possibility to increase backyard production is limited by the availability of the feed materials these systems rely on. There is, however, a strong mitigation potential in upgrading intermediate systems to improve herd efficiency. Furthermore, independent of the production system, manure storage, processing and application practices can be altered to mitigate emissions.

For chicken, the broiler and layer systems display lower levels of emission intensity than backyard systems for meat and eggs. Feed represents about 75 percent of emissions in intensive systems, so the type and origin of feed materials explain most of the emission intensity variability within these systems.

KEY MESSAGES OF CHAPTER 5

- The potential to reduce the sector's emissions is large. Technologies and practices that help reduce emissions exist but are not widely used. The adoption and use of best practices and technologies by the bulk of the world's producers can result in significant reductions in emissions.

- Emission intensities (emissions per unit of animal product) vary greatly between production units, even within similar production systems. Different agro-ecological conditions, farming practices and supply chain management explain this variability. In the gap between the production units with the lowest emission intensities and those with the highest emission intensities is potential for mitigation.

- The emissions could be reduced by between 18 and 30 percent (or 1.8 to 1.1 gigatonnes CO_2-eq), if producers in a given system, region and climate adopted the practices currently applied by the 10 to 25 percent of producers with the lowest emission intensity.

- Better grazing land management holds additional promises for mitigation. It can contribute to carbon sequestration of up to 0.4 to 0.6 gigatonnes CO_2-eq.

- The mitigation potential can be achieved within existing systems; this means that the potential can be achieved thanks to improving practices rather than changing production systems (i.e. shifting from grazing to mixed or from backyard to industrial).

- A reduction of emissions can be achieved in all climates, regions and production systems.

- The adoption of more efficient technologies and practices is key to reducing emissions. Possible interventions to reduce emissions are to a large extent based on technologies and practices that improve production efficiency at animal and herd levels. They include better feeding practices to reduce enteric and manure emissions, better husbandry and health management to reduce the unproductive part of the herd (fewer animals means fewer inputs, fewer rejections and fewer emissions for the same level of production).

- Manure management practices that ensure the recovery and recycling of nutrients and energy contained in manure and a more efficient use of energy along supply chains are also mitigation options.

- Most of the technologies and practices that mitigate emissions also improve productivity and can contribute to food security and poverty alleviation as the planet needs to feed a growing population.

- The major mitigation potential lies in ruminant systems operating at low productivity, for example, in Latin America and the Caribbean, South Asia and sub-Saharan Africa. Part of the mitigation potential can be achieved through better animal and herd efficiency.

- Mitigation potential is also important in intermediate pig production systems of East and Southeast Asia.

- The most affluent countries, where emission intensities of ruminant production are relatively lower but the volumes of production and emissions remain important, also offer an important potential for mitigation. In these areas where herd efficiency is often already high, mitigation can be achieved by on-farm efficiency, such as better manure management and energy saving devices.

SCOPE FOR MITIGATION

Reducing the sector's emissions may be achieved by reducing production and consumption, by lowering emission intensity of production, or by a combination of the two.

This assessment does not investigate the potential of reduced consumption of livestock products. Several authors have, however, assessed the hypothetical mitigation potential of different dietary change scenarios (see, for example, Stehfest *et al.*, 2009; Smith *et al.*, 2013); their work demonstrates the substantial mitigation effect, and its relatively low cost, compared with alternative mitigation strategies. Positive effects of reducing animal protein consumption on human health are also reported among populations consuming high levels of animal products (McMichael *et al.*, 2007; Stehfest *et al.*, 2009).

Many technical options exist for the mitigation of GHG emissions along livestock supply chains. They fall into the following categories: 1) options related to feed supplements and feed/feeding management (for CH_4 only); 2) options for manure management which include dietary management, but with a focus on "end-of-pipe" options for the storage, handling and application phases of manure management; 3) animal husbandry options which include animal and reproductive management practices and technologies. The practices and technologies recommended by (FAO, 2013c) for their effectiveness are reported in Box 2.

5.1 MITIGATION POTENTIAL

Earlier sections have described the high variability of emission intensity on a global and regional scale, identifying a wide gap in emission intensity between the producer with the lowest emission intensity and the producer with the highest emission intensity. This gap is also found within discrete sets of commodity, production system, regions and agro-ecological zones, as illustrated in Figures 25 and 26.

This gap provides room to mitigate emissions within existing systems.

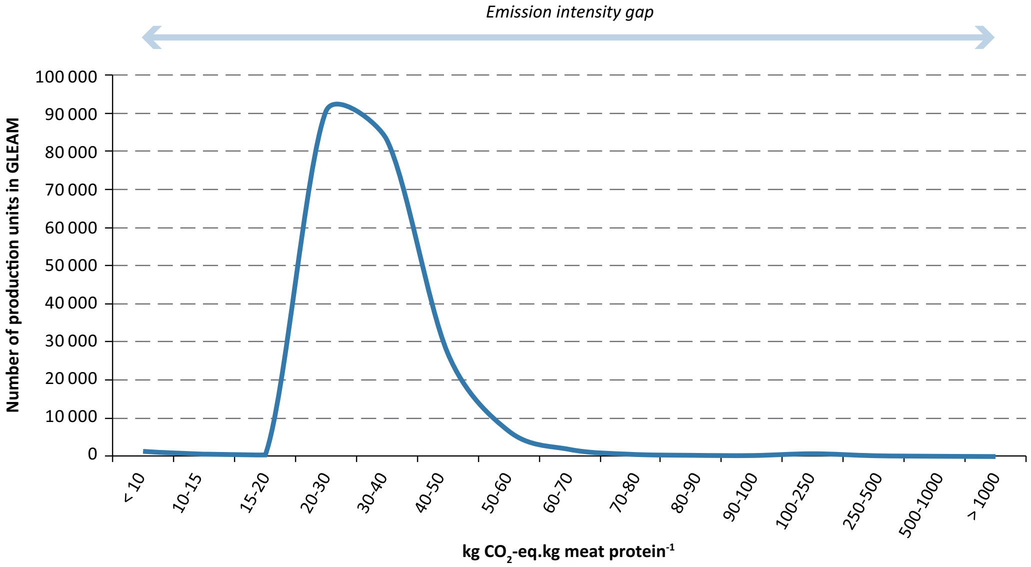
Order of magnitude

The sector's potential to mitigate GHG emissions is important, and significant reductions could be obtained by closing the gap in emission intensities among producers in the same region and production systems.

Mitigation potential within existing production systems

It is estimated that the sector's emissions could be reduced by approximately 30 percent (about 1.8 gigatonnes CO_2-eq) if producers in a given system,

FIGURE 25. Example of emission intensity gap – distribution of broiler production units in GLEAM according to their emission intensity in temperate zones of East and Southeast Asia



Source: GLEAM.

region and agro-ecological zone were to apply the practices of the 10 percent of producers with lowest emission intensity (10th percentile)[18] (Table 10), while keeping the overall output constant. If producers were to apply the practices of the 25 percent of producers with lowest emission intensity (25th percentile), the sector's emissions could be reduced by 18 percent (about 1.1 gigatonnes CO_2-eq). These estimates are based on several assumptions, including that conducive policies and market signals are in place to overcome barriers to the adoption of the most efficient production practices. These numbers should be taken as an order of magnitude only and need to be considered in view of the many assumptions and simplifications that this aggregated gap analysis entails (Box 3).

This mitigation potential does not imply any farming system change and is based on existing and already applied technologies.

This large mitigation potential is observed for the various species. Emission reductions are roughly proportional to current emissions by different species: cattle offer the largest potential (65 percent) followed by chicken (14 percent), buffalos (8 percent), pigs (7 percent) and small ruminants (7 percent).

It should be noted that the mitigation potential is estimated at constant output. The sector is, however, growing and projected to further expand in the coming decades. Furthermore, disseminating the production practices of the 10th (25th) quantile in a given system, region and climate to all the producers in that region may well boost productivity. Net mitigation effect will be shaped by the combination of emission intensity reductions and output growth.

Mitigation potential allowing for changes between production systems

Allowing for moves between production systems (but not between commodity or region and agro-ecological zone), would achieve modest additional benefits (Table 10). Emissions would be

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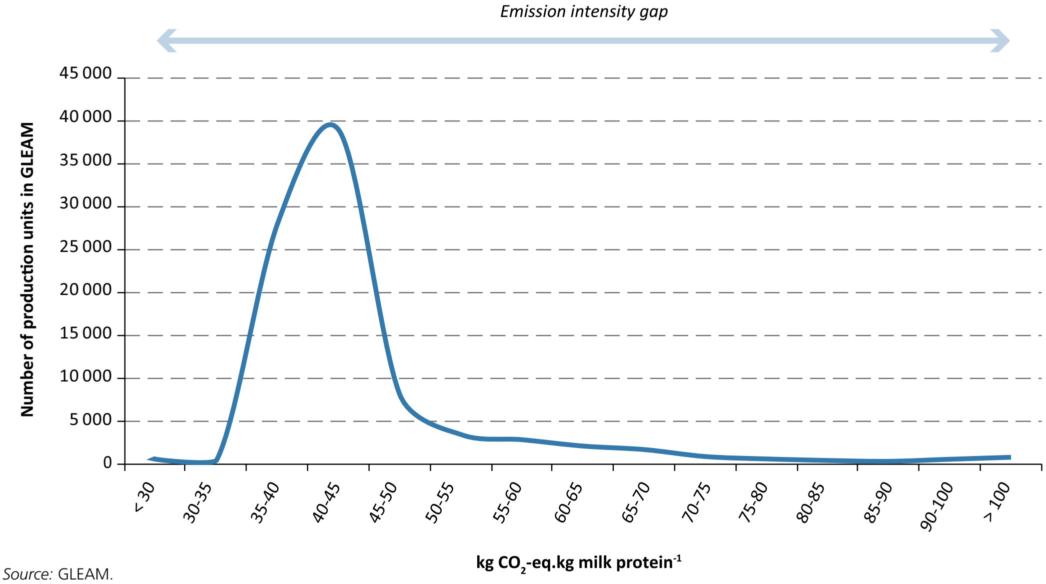
[18] Average emission intensity of each unique combination of commodity, production system, region and agro-ecological zone set to the level of the lowest 10th (25th) percentile.

FIGURE 26. Example of emission intensity gap – distribution of dairy cattle production units in GLEAM according to their emission intensity in mixed systems in temperate zones of Western Europe



Source: GLEAM.

reduced by 32 percent if all producers in a given region and climate were to apply the practices of the 10th percentile,[19] and by 20 percent if they were to apply the practices of the 25th percentile.

This indicates that the heterogeneity of practices and resulting gap in emission intensities within the broad production systems used for this analysis are nearly as broad as the heterogeneity of practices between production systems.

If the mitigation potential identified in this assessment does not require any system change, nor any change in the mix of products generated by the sector (i.e. milk, eggs, beef, etc.), these changes are de facto taking place and affect the overall emission intensity of livestock. The two commodities currently showing highest growth rates are among those with lowest global average emission intensity, namely milk and poultry (FAOSTAT, 2013), which will tend to reduce average emission intensity per unit of protein. This is further accentuated by the fact that most of the growth is taking place among high productivity (dairy) and intensified (industrial broilers and layers) systems, which generally have the lowest emission intensity.

A conservative estimate

The emission reduction estimated through the statistical analysis of emission intensity gap reflects the hypothetical case of average emission intensities raised to the level of the 10 and 25 percent of best-performing production units, respectively. Despite the limitations of this statistical analysis and the assumptions on which it relies regarding policy context and availability of resources (see Box 3), it is probable that the resulting estimate is conservative.

First, it excludes mitigation technologies and practices that are available but not yet applied or adopted by more than a small share of producers and, thus, not included in the baseline. This is, for example, the case of biodigesters in ruminant production, energy saving devices on dairy farms or dietary supplements to reduce enteric CH_4 emissions.

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[19] Average emission intensity of each unique combination of commodity, region and agro-ecological zone set to the level of the lowest 10th (25th) percentile.

BOX 2. A REVIEW OF AVAILABLE TECHNIQUES AND PRACTICES TO MITIGATE NON-CO_2 EMISSIONS

FAO recently initiated a comprehensive literature review of available mitigation techniques and practices for livestock (FAO, 2013c; Gerber *et al.*, 2013). The review focuses on mitigation options for enteric CH_4 and manure CH_4 and N_2O emissions. Tables A, B and C give a summary of this review.

Diet manipulation and feed additives have been identified as main avenues for the mitigation of enteric CH_4 production. Their effectiveness on absolute emissions is generally estimated to be low to medium, but some of these options can achieve substantially lower emission intensity by improving feed efficiency and animal productivity. Diets also affect manure emissions, by altering the content of manure: ration composition and additives have an influence on the form and amount of N in urine and faeces, as well as on the amount of fermentable organic matter in faeces.

Methane emissions from manure can be effectively controlled by shortening storage duration, ensuring aerobic conditions or capturing the biogas emitted in anaerobic conditions. However, direct and indirect N_2O emissions are much more difficult to prevent once N is excreted. Techniques that prevent emissions during initial stages of management preserve N in manure that is often emitted at later stages. Thus, effective mitigation of N losses in one form (e.g. NH_3) is often offset by N losses in other forms (e.g. N_2O or NO_3). These transference effects must be considered when designing mitigation practices. Numerous interactions also occur among techniques for mitigating CH_4 and N_2O emissions from manure.

More research is needed to develop practical and economically-viable mitigation techniques that can be widely practised. Efforts should target single practices with high potential (e.g. vaccination against rumen methanogens), but also take into account the interactions between practices, to develop suites of effective mitigation practices for specific production systems.

TABLE A. Available techniques and practices for non-CO_2 mitigation: feed additives and feeding practices

Practice/technology	Potential CH_4 mitigating effect[1]	Long-term effect established	Environmentally safe or safe to the animal
Feed additives			
Nitrate	High	No?	NK
Ionophores	Low	No?	Yes?
Plant bioactive compounds			
Tannins (condensed)	Low	No?	Yes
Dietary lipids	Medium	No?	Yes
Manipulation of rumen	Low	No	Yes?
Concentrate inclusion in ration	Low to Medium	Yes	Yes
Forage quality and management	Low to Medium	Yes	Yes
Grazing management	Low	Yes	Yes
Feed processing	Low	Yes	Yes
Macro-supplementation (when deficient)	Medium	Yes	Yes
Micro-supplementation (when deficient)	NA	No	Yes
Breeding for straw quality	Low	Yes	Yes
Precision-feeding and feed analyses	Low to Medium	Ye	Yes

[1] High = ≥ 30 percent mitigating effect; Medium = 10 to 30 percent mitigating effect; Low = ≤ 10 percent mitigating effect. Mitigating effects refer to percentage change over a “standard practice”, i.e. study control that was used for comparison and based on a combination of study data and judgement by the authors of this document.

NK = Unknown.

NA = Not applicable.

? = Uncertainty due to limited research, variable results or lack of/insufficient data on persistence of the effect.

TABLE B. Available techniques and practices for non-CO_2 mitigation: manure handling

Practice/technology	Species[1]	Potential CH_4 mitigating effect[2]	Potential N_2O mitigating effect[2]	Potential NH_3 mitigating effect[2]
Dietary manipulation and nutrient balance				
Reduced dietary protein	AS	?	Medium	High
High fibre diets	SW	Low	High	NK
Grazing management	AR	NK	High?	NK
Housing				
Biofiltration	AS	Low?	NK	High
Manure system	DC, BC, SW	High	NK	High
Manure treatment				
Anaerobic digestion	DC, BC, SW	High	High	Increase?
Solids separation	DC, BC	High	Low	NK
Aeration	DC, BC	High	Increase?	NK
Manure acidification	DC, BC, SW	High	?	High
Manure storage				
Decreased storage time	DC, BC, SW	High	High	High
Storage cover with straw	DC, BC, SW	High	Increase?	High
Natural or induced crust	DC, BC	High	Increase?	High
Aeration during liquid manure storage	DC, BC, SW	Medium to High	Increase?	NK
Composting	DC, BC, SW	High	NK	Increase
Litter stacking	PO	Medium	NA	NK
Storage temperature	DC, BC	High	NK	High
Sealed storage with flare	DC, BC, SW	High	High	NK
Manure application				
Manure injection vs surface application	DC, BC, SW	No Effect to Increase?	No Effect to Increase	High
Timing of application	AS	Low	High	High
Soil cover, cover cropping	AS	NK	No Effect to High	Increase?
Soil nutrient balance	AS	NA	High	High
Nitrification inhibitor applied to manure or after urine deposition in pastures	DC, BC, SH	NA	High	NA
Urease inhibitor applied with or before urine	DC,BC, SH	NA	Medium?	High

[1] DC = dairy cattle; BC = beef cattle (cattle include *Bos taurus* and *Bos indicus*); SH = sheep; GO = goats; AR = all ruminants; SW = swine; PO = poultry; AS = all species.

[2] High = ≥ 30 percent mitigating effect; Medium = 10 to 30 percent mitigating effect; Low = ≤ 10 percent mitigating effect. Mitigating effects refer to percentage change over a "standard practice", i.e. study control that was used for comparison and based on combination of study data and judgement by the authors of this document.

NK = Unknown.

NA = Not applicable.

? = Uncertainty due to limited research, variable results or lack of/insufficient data on persistency of the effect.

(cont.)

BOX 2. *(cont.)*

TABLE C. Available techniques and practices for non-CO_2 mitigation: animal husbandry

Practice/technology	Species[1]	Effect on productivity	Potential CH_4 mitigating effect[2]	Potential N_2O mitigating effect[2]
Animal management				
Genetic selection (Residual feed intake)	DC, BC, SW?	None	Low?	NK
Animal health	AS	Increase	Low?	Low?
Reduced animal mortality	AS	Increase	Low?	Low?
Optimization of age at slaughter	AS	None	Medium	Medium
Reproductive management				
Mating strategies	AR, SW	High to medium	High to medium	
Improved productive life	AR, SW	Medium	Medium	
Enhanced fecundity	SW, SH, GO	High to medium	High to medium	
Periparturient care/health	DC AR, SW	Medium	Medium	
Reduction of stress	AR, SW	High to medium	High to medium	
Assisted reproductive technologies	AR, SW	High to medium	High to medium	

[1] DC = dairy cattle; BC = beef cattle (cattle include *Bos taurus* and *Bos indicus*); SH = sheep; GO = goats; AR = all ruminants; SW = swine; PO = poultry; AS = all species.

[2] High = ≥ 30 percent mitigating effect; Medium = 10 to 30 percent mitigating effect; Low = ≤ 10 percent mitigating effect. Mitigating effects refer to percentage change over a "standard practice", i.e. study control that was used for comparison and based on combinations of study data and judgement by the authors of this document.

NK = Unknown.

? = Uncertainty due to limited research, variable results or lack of/insufficient data on persistence of the effect.

Second, the gap analysis does not capture the potential offered by practices for which GLEAM uses average input data over entire combinations of production systems, regions and agro-ecological zones. For example, several parameters related to herd performance that characterize animal husbandry practices and animal health are defined at regional or farming system levels.

And third, the analysis excludes postfarm emissions and emissions related to pasture expansion that are not calculated at pixel level. Together, they represent about 10 percent of the 7.1 gigatonnes.

5.2 CARBON SEQUESTRATION

Reduced land-use change

Reducing land-use changes can further contribute to mitigation. Emissions from pasture and soybean area expansion result in an estimated 9 percent of the sector's emissions (Chapter 2). While no formal analysis was done to estimate global abatement potential from land-use change, it is plausible that land-use conversion rates related to livestock production could be halved over the medium term (one to two decades), mitigating about 0.4 gigatonnes CO_2-eq of the sector's annual emissions. The feasibility of this target is demonstrated by comparison with the Brazilian Government's pledge in 2010 to reduce emissions by 0.7 gigatonnes CO_2-eq, by reducing deforestation rates by 80 percent in the Amazon and by 40 percent in the Cerrado by 2020.[20] In the mitigation case study for the specialized beef sector in Brazil presented later, animal and herd efficiency improvements were estimated to reduce grazing land use and associated land-use change emissions by up to 25 percent.

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[20] http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/brazilcphaccord_app2.pdf; http://www.brasil.gov.br/cop-english/overview/what-brazil-is-doing/domestic-goals

TABLE 10. Estimates of emission reduction potential based on the analysis of emission intensity gap

	Analysis within unique sets of geographical region, climate and farming system (farming system change excluded)						**Analysis within unique sets of geographical region and climate (farming system change allowed)**					
	Production units align to average emission intensity of the 10th percentile			Production units align to average emission intensity of the 25th percentile			Production units align to average emission intensity of the 10th percentile			Production units align to average emission intensity of the 25th percentile		
	Emission reduction											
	By species *(Million tonnes CO_2-eq)*	By species *(percentage)*	In the scenario *(percentage)*	By species *(Million tonnes CO_2-eq)*	By species *(percentage)*	In the scenario *(percentage)*	By species *(Million tonnes CO_2-eq)*	By species *(percentage)*	In the scenario *(percentage)*	By species *(Million tonnes CO_2-eq)*	By species *(percentage)*	In the scenario *(percentage)*
Beef cattle	-775	-27	44	-482	-17	44	-883	-31	45	-619	-22	51
Dairy cattle	-401	-32	23	-231	-18	21	-440	-35	23	-264	-21	22
Pig	-103	-19	6	-76	-14	7	-108	-19	6	-69	-14	6
Buffalo meat	-96	-41	5	-31	-13	3	-101	-43	5	-32	-14	3
Buffalo milk	-80	-22	4	-51	-14	5	-89	-25	5	-54	-15	4
Chicken eggs	-66	-38	4	-51	-29	5	-73	-42	4	-50	-29	4
Chicken meat	-113	-40	6	-97	-34	9	-94	-33	5	-60	-21	5
Small rum. milk	-45	-36	3	-24	-19	2	-49	-39	3	-17	-14	1
Small rum. meat	-96	-31	5	-50	-16	5	-105	-33	5	-58	-18	5
Total	**-1 775**	**-29**	**100**	**-1 092**	**-18**	**100**	**-1 943**	**-32**	**100**	**-1 224**	**-20**	**100**

BOX 3. ESTIMATING MITIGATION POTENTIAL THROUGH ANALYSIS OF THE EMISSION INTENSITY GAP

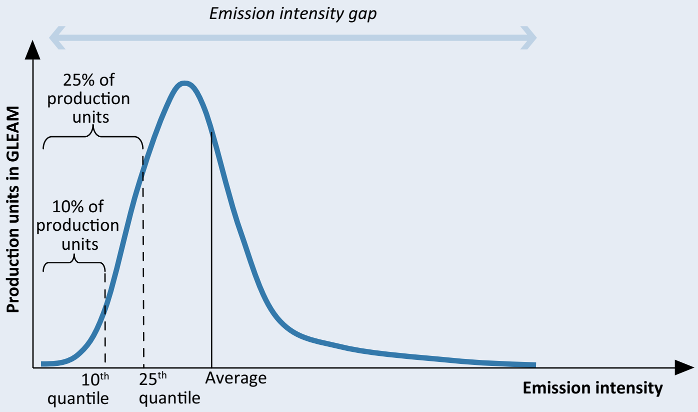
For each commodity, produced in a specific combination of geographical region, climate and farming system, the average emission intensity and the emission intensity of the 10th and 25th percentiles of production units (pixels) showing the lowest emission intensity were computed. The mitigation potential was then estimated by shifting the baseline average emission intensity to either the lowest 10th or 25th percentile (representing production units with lower emission intensity).

The mitigation potential was also computed allowing for changes in farming systems: average and percentile were assessed for each commodity, produced in a discrete combination of geographical region and agro-ecological zone.

This statistical analysis relies on the following assumptions:

- Conducive policies and market signals are in place to overcome barriers to the adoption of most efficient production practices.
- Extending the mix of inputs used by the 25 percent or 10 percent best performing units to all production units in the region/climate/system does not alter the emission intensity of that mix of inputs.
- There is no local resource constraint (e.g. microclimate, water) to the adoption of low emission intensity practices.
- Resources (e.g. commercial feed, energy) are available at regional level to enable the adoption of low emission intensity practices.

Schematic representation of emission intensity distribution and emission intensity gap, for a given commodity, within a region, climate zone and farming system



Grassland soil carbon sequestration

It is estimated that improved grazing management practices in grasslands could sequester about 409 million tonnes CO_2-eq of carbon per year (or 111.5 million tonnes C per year over a 20-year time period), globally. A further 176 million tonnes CO_2-eq of sequestered emissions (net of increased N_2O emissions) per year over a 20-year time period, was estimated to be possible through the sowing of legumes in some grassland areas. Thus, a combined mitigation potential of 585 million tonnes CO_2-eq was estimated from

Credit: ©FAO/Giulio Napolitano

these practices, representing about 8 percent of livestock supply chain emissions. Chapter 2 presents an introduction to the methodology used.

In grasslands that have experienced the excessive removal of vegetation and soil carbon losses from sustained periods of overgrazing, historical carbon losses can at least be partially reversed by reducing grazing pressure. Conversely, there is also scope to improve grass productivity and sequester soil carbon by increasing grazing pressure in many grasslands that are only lightly grazed (Holland *et al.*, 1992).

There are several other practices which could be used to further increase grassland soil carbon stocks, which were not assessed in this study. They include the sowing of improved, deep-rooted tropical grass species and improved fire management.

According to the 4th Assessment Report to the IPCC (Smith *et al.*, 2007), 1.5 gigatonnes CO_2-eq of carbon could be sequestered annually if a broad range of grazing and pasture improvement practices were applied to all of the world's grasslands. The same study estimates that up to 1.4 gigatonnes CO_2-eq of carbon can be sequestered in croplands annually, and much of these are devoted to feed production. In another global grassland assessment, Lal (2004) estimated a more conservative potential for carbon sequestration of between 0.4 and 1.1 gigatonnes CO_2-eq per year. The sequestration potential estimated in this assessment falls within the range of these global estimates.

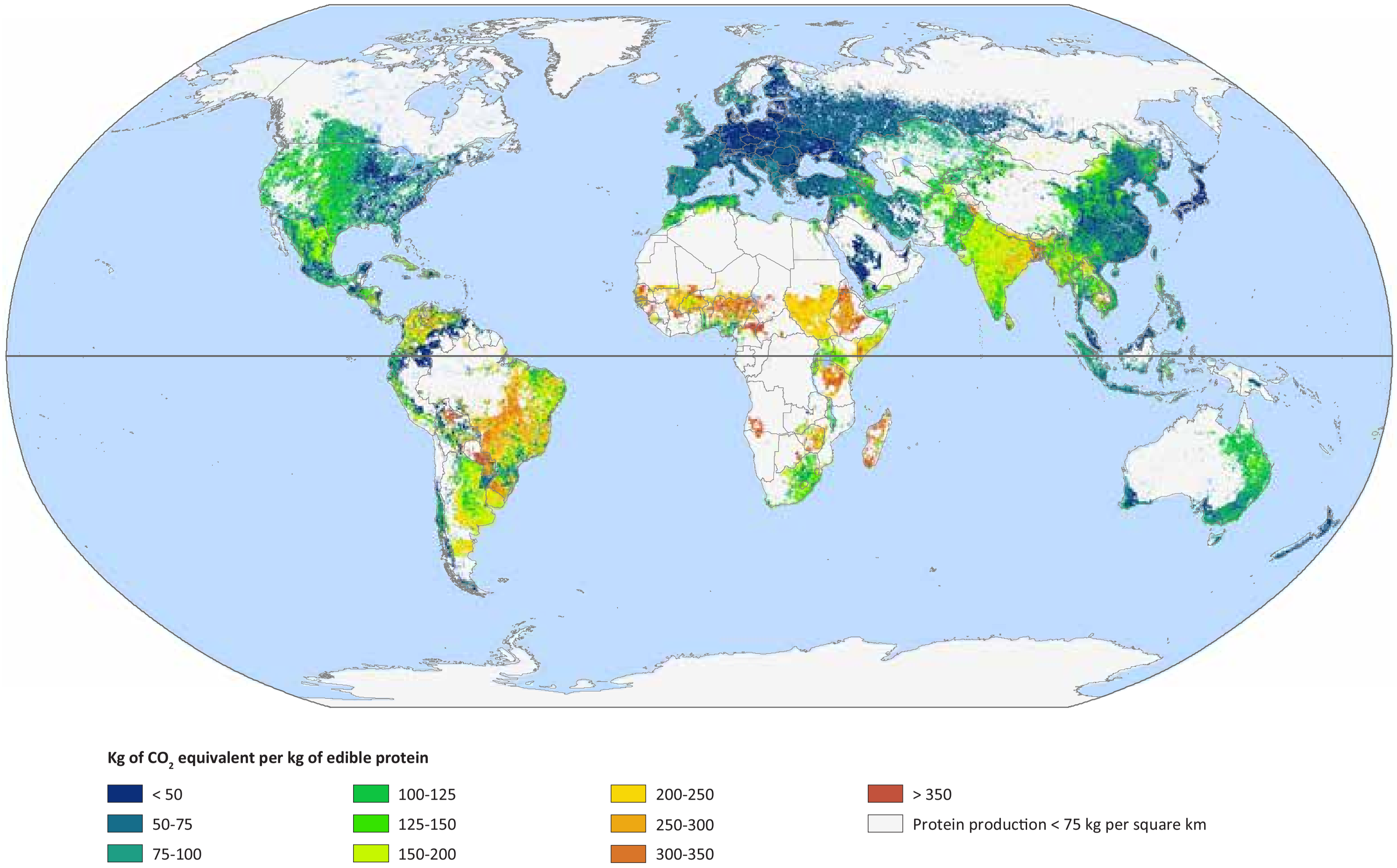
5.3 POTENTIAL BY MAIN GEOGRAPHICAL AREAS

The mitigation potential varies amongst regions depending on production volume and related emission intensities. Emissions per unit of animal protein and emissions per unit of land are displayed on maps in Figure 27A, B, and C.

Areas for which both emissions per unit of animal protein and per unit of land are low (e.g. parts of Central Europe, Middle East and Andean regions) are generally areas where little production takes place, mostly relying on monogastric species, and it can be assumed that these areas offer relatively low potential for mitigation.

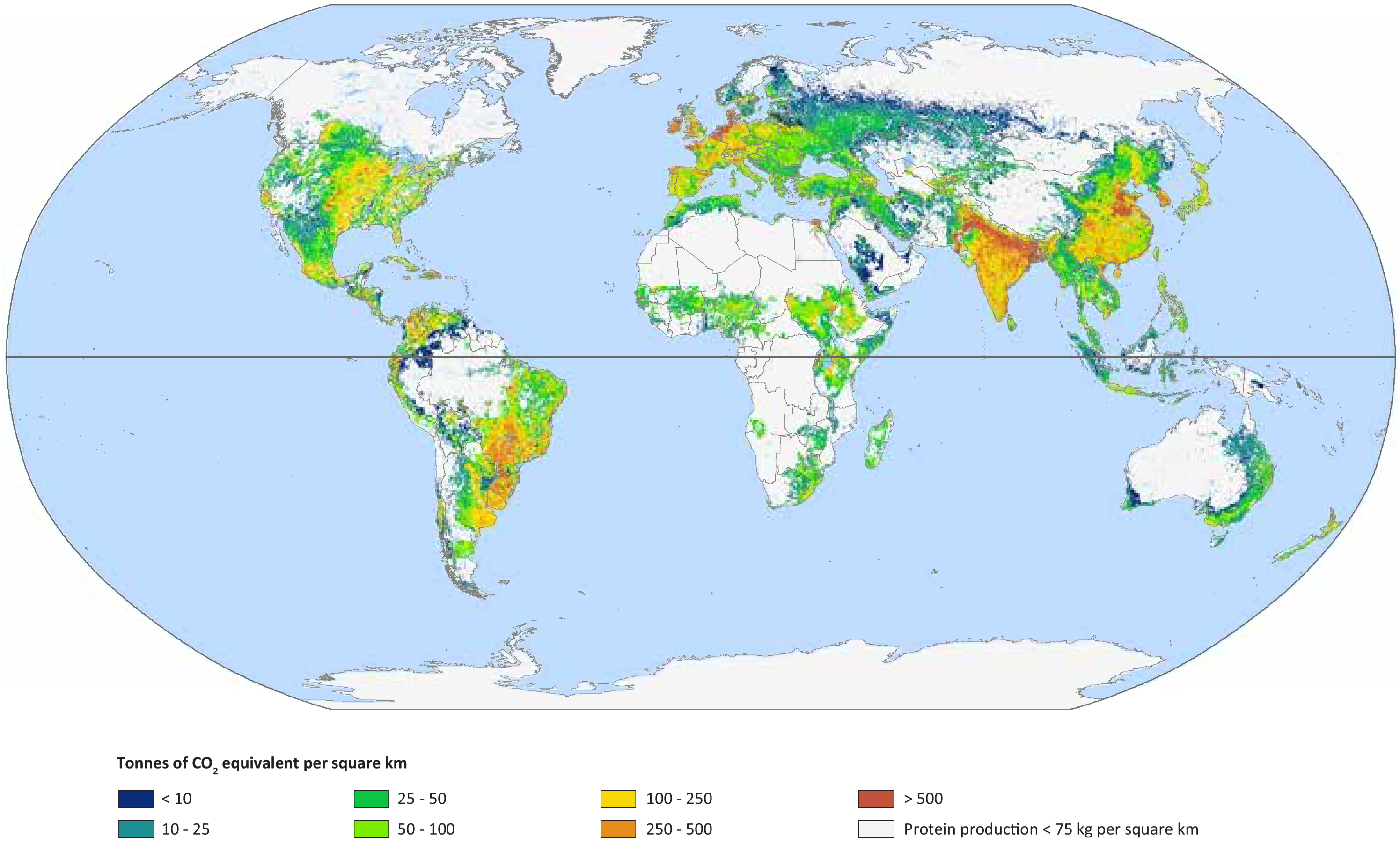
The most affluent areas of the globe usually combine low emission intensity per unit of product with high emission intensity per area of land. Here, relatively marginal emission intensity gains can result in a significant mitigation effect, given the sheer volume of emissions.

FIGURE 27A. Emission intensity per unit of edible protein



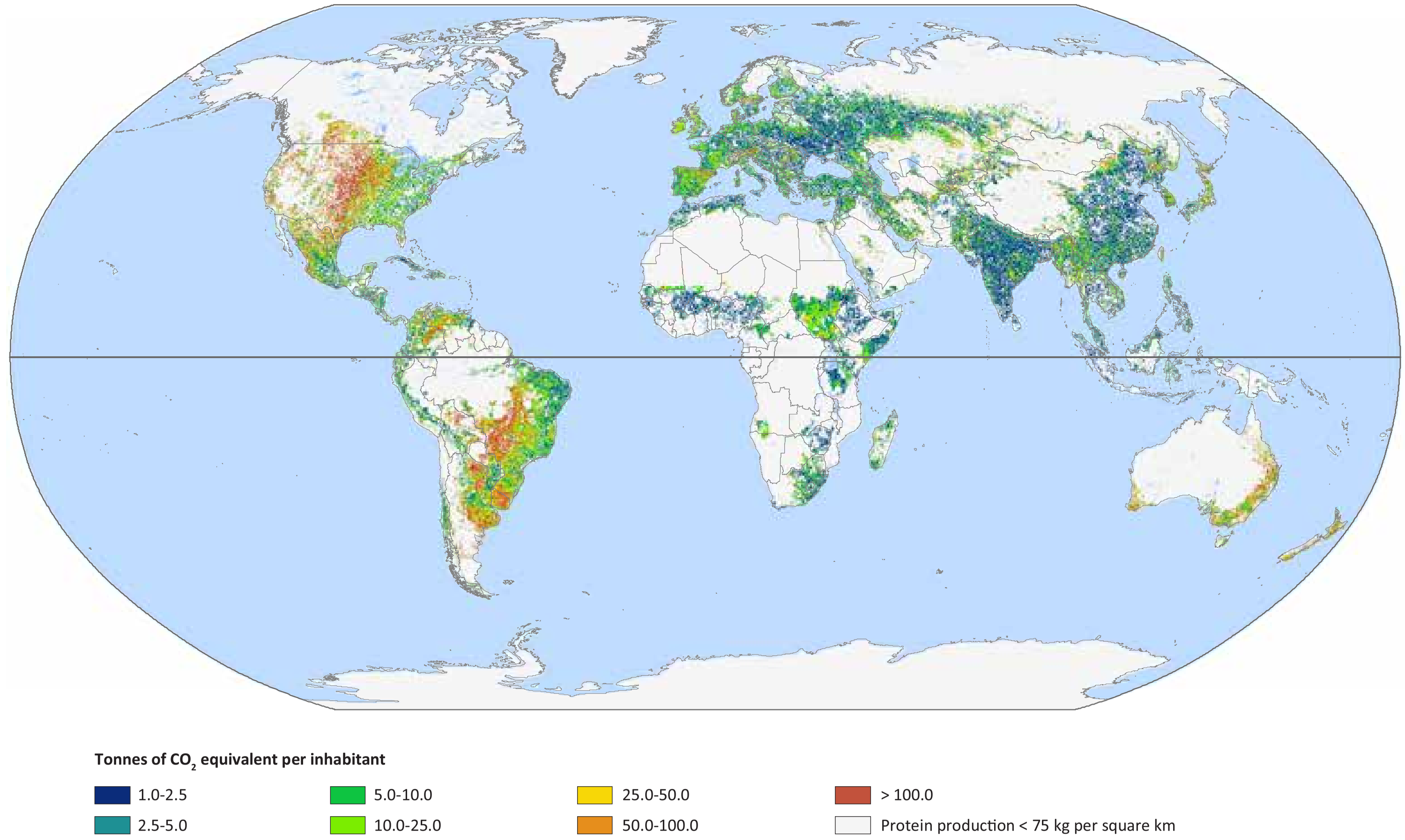
Source: GLEAM.

FIGURE 27B. Emission intensity per unit of land area



Source: GLEAM.

FIGURE 27C. Emission intensity per unit of human population



Source: GLEAM; GIS data for human population: Dobson *et al.*, 2000.

Large areas in the subhumid and semi-arid zones of Africa and Latin America display high emission intensity per unit of protein but low emission intensity when expressed per unit of land. Mitigation is achievable in these areas but should be considered in view of food security and climate change adaptation concerns. Even modest productivity improvements in ruminant systems and improved grazing practices could yield substantial gains in both emission intensities and food security. However, many of these areas suffer from remoteness and climate variability that limit the opportunities to adopt new practices. Specific policies are required to overcome these constraints, as outlined in Chapter 7.

The major technical mitigation potential is probably to be found in areas where both measures of emission intensity are high. They are mainly found in Latin America and South Asia, and in parts of Eastern Africa. Here, a large potential for emission reduction per unit of protein coincides with substantial volumes of production. These areas are generally characterized by high cattle densities and low animal productivity. The range of mitigation options discussed above apply here, including animal performance improvement (e.g. genetics, health), feeding practices (e.g. digestibility of ration, protein content), herd structure management (e.g. reducing breeding overhead), manure management (storage, application, bio-digestion) and land management (improved pasture management).

Another way to express emission intensity is to relate total emissions from the livestock sector to human population (Figure 27C). Emission intensity values are relatively high where animals are produced in sparsely populated areas, typically for commercial grazing beef systems, such as parts of North America, Latin America and Oceania. Here, the economic and social implication of any mitigation intervention will need particular attention because livestock is among the major economic activities. Effects on local communities through income, risk and competitiveness issues will be of particular relevance.

KEY MESSAGES OF CHAPTER SIX

- Packages of mitigation techniques can bring large environmental benefits as illustrated in five case studies conducted to explore mitigation in practice. The mitigation potential of each of the selected species, systems and regions ranges from 14 to 41 percent.*

- While comparably high mitigation potentials were estimated for the ruminant and pig production systems in Asia, Latin America and Africa, significant emission reductions can also be attained in dairy systems with already high levels of productivity, as demonstrated by the case study on OECD countries.

- Some of the illustrated mitigation interventions can concomitantly lead to a reduction of emission intensities and volumes and an increase in both productivity and production. This is particularly the case with improved feeding practices, better health and herd management practices.

Main conclusions from case studies

- In South Asian mixed dairy farming systems, GHG emissions can potentially be reduced by 38 percent of the baseline emission (120 million tonnes CO_2-eq) with feasible improvements in feed quality, animal health and husbandry.

- In industrial pig production systems in East and Southeast Asia, emissions could be reduced by 16 to 25 percent of baseline emissions for these systems (21 to 33 million tonnes CO_2-eq) with feasible improvements in manure management and the adoption of energy saving technologies and low carbon energy. In intermediate systems, where the options of improved herd management and feed were also tested, emissions could be reduced by 32 to 38 percent of baseline emissions (32 to 37 million tonnes CO_2-eq). About half of the mitigation is achieved by improving feed quality and animal performances.

- In specialized beef production in South America, feasible improvements in forage quality, animal health and husbandry and grazing management could lead to an emissions reduction of 19 to 30 percent of baseline emissions (190 to 310 million tonnes CO_2-eq).

- In the West African small ruminant sector, emissions can potentially be reduced by 27 to 41 percent of total annual baseline emissions (7.7 to 12 million tonnes CO_2-eq) with feasible improvements in forage digestibility, animal health, husbandry and breeding, and grazing management.

- In dairy mixed systems in OECD countries, emissions could be reduced by 14 to 17 percent of the baseline GHG emissions (54 to 66 million tonnes CO_2-eq) with feasible adoption of improved manure management systems, feed supplementation and energy saving equipment.

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* These ranges of mitigation support the findings from the statistical assessment in Chapter 5 which estimated global emission reductions of between 18 percent to 30 percent, based on closing gaps in emission intensities. It is also worth mentioning that these technical mitigation potentials are in line with local assessments and commitments (see for example the Low Carbon Agriculture (ABC) programme of Brazil and dairy production in the United States of America and the United Kingdom of Great Britain and Northern Ireland mentioned in Chapter 6).

MITIGATION IN PRACTICE: CASE STUDIES

Five case studies were developed to complement the statistical analysis of emission intensity gaps (Chapter 5) and explore how the estimated mitigation potential could be achieved in practice. The case studies evaluated the mitigation potentials of specific technical interventions in selected production systems and geographical areas.

Each case study provides an illustration of possible mitigation interventions, based on the understanding of main drivers of emissions and related technical entry points for mitigation, such as herd level productivity gains, energy use efficiency or "end-of-pipe" manure management measures (Box 2). They do not provide estimates of the total technical mitigation potential in the considered systems (i.e. the maximum mitigation effect achieved by adopting all available technologies, whatever their cost).

A short- to medium-term time horizon is assumed in the studies in terms of the mitigation interventions that were selected. The mitigation potentials were calculated by modifying parameters in GLEAM related to these interventions, holding output constant.

Choice of sectors. Four of the five case studies are focused on ruminant supply chains (cattle and small ruminants), given their large relative contribution to overall emissions; one of the case studies explores the mitigation potential in pork production.

Choice of mitigation options. The purpose of the case studies is to illustrate what could be achieved using a small selection of feasible options in very different production systems, rather than to provide an exhaustive assessment of all available mitigation options for the sector.

The mitigation options assessed were selected according to their high mitigation potential and their feasibility of adoption by farmers, in the respective regions and production systems. They focus on packages of available techniques that have proven to be effective over the short to medium term and that are anticipated to provide important productivity benefits. Interventions were also selected in view of their anticipated economic feasibility, their positive implications on food security and considering potential trade-offs with other environmental concerns.

A number of mitigation techniques that have also been recommended by practitioners were not assessed. Among them, the supplementation of ruminants with grain concentrate is perhaps the most widely tested option (FAO, 2013c). However, this option was excluded due to concerns about its economic feasibility and its potential to threaten food security by reducing grain available for human food consumption. Moreover, in order to include this option, a much broader analysis would have been required, accounting for the varying impacts of different concentrate feed sources on land-use change and emissions in general, which was considered to be beyond the scope of this study.

Given more time, other effective and available mitigation options, such as improvements in breeds to increase animal productivity, could also be considered. Furthermore, there are potentially effective options that need further development such as the use of anti-methanogen vaccines, which would also deserve consideration under a longer assessment time horizon. Such possible vaccines have been assessed in other studies (Whittle *et al.,* 2013; Moran *et al.,* 2008; Beach *et al.,* 2008), and are considered to have great potential in extensive ruminant systems, because they would require very infrequent inoculations and minimal management. However, this option requires further research and its commercial availability is unlikely in the near future (FAO, 2013c).

A number of controversial growth promoting compounds, such as ionophores and bST, that have been estimated to be effective mitigation options in other studies (USEPA, 2006; Moran *et al.,* 2011; Smith *et al.,* 2007), were also excluded from this analysis, due to bans on their use in important markets (e.g. European Union) and uncertainties about their human health implications.

Supplementation of animal rations with synthetic amino acids, such as lysine in pig production, was also omitted in view of its cost, although it is often described as increasing efficiency and manure NH_3 and N_2O mitigation (FAO, 2013c).

Mitigation potential calculated with constant production level. For the sake of clarity, and given the focus on emission intensity, production volumes were held constant while computing the mitigation scenarios in GLEAM. Some of the mitigation interventions illustrated in the case studies would nevertheless result in a concomitant increase of productivity and efficiency. These effects are discussed in the final section of this chapter.

Limitations. By design, the mitigation assessments put aside considerations of the possible barriers to adoption.

In the absence of financial incentives (e.g. mitigation subsidies) or regulations to limit emissions, most producers are unlikely to invest in mitigation practices unless they increase profits or provide other production benefits such as risk reduction. In this respect, a cost-benefit analysis of the selected mitigation practices would be needed to estimate the emission reductions that could be achieved in an economically viable way. In addition, other barriers to adoption, including the technical capacity of producers, extension agents and institutions, and the availability of capital and infrastructure to support adoption of the selected mitigation measures, would also have to be considered to better understand the feasible adoption rates of the assessed mitigation practices. The policy implications and requirements to overcome these barriers are explored in more detail in the following chapter.

The adoption of GHG mitigation interventions may also have side effects (positive or negative) on other environmental impacts (e.g. preservation of water resources and land-use change), animal welfare and wider development goals (e.g. food security and equity), which need to be assessed and integrated as part of livestock sector policies. These factors are not modelled in the case studies; however, the selection of mitigation practices and, in some cases, assumptions about their level of adoption were made in view of some of these constraints and issues. For example, by improving animal and herd productivity, most of the selected mitigation practices have the capacity to simultaneously increase production and reduce emissions, and thus avoid conflicts between environmental, development and food security objectives.

6.1 DAIRY CATTLE PRODUCTION IN SOUTH ASIA

Main characteristics

Production

With about 12 percent of global production, South Asia is one of the world's major cattle milk-producing regions.[21] India alone produces 75 percent of the regional output and is likely to maintain its predominance with an expected milk production growth of 3 percent per year over the period 2011–2020. In India, most states outlaw the slaughter of cattle for cultural and religious reasons. As a result, there is a persistent share of unwanted male dairy calves with high mortality rates, which represent a productive loss to the supply chain.

Twenty-eight percent of all dairy cattle are found in mixed systems in South Asia, compared with 10 percent and 4 percent in Western Europe and North America, respectively. About 93 percent of the regional milk output is produced in mixed farming systems. South Asian dairy mixed systems account for 13 and 23 percent of global milk production and GHG emissions from dairy mixed systems, respectively.

Emissions

Major sources of emissions include CH_4 from enteric fermentation, which accounts for 60 percent, and N_2O from feed production (from applied and deposited manure and synthetic fertilizer use), accounting for 17 percent.

The average emission intensity in mixed farming systems in South Asia is estimated at 5.5 kg CO_2-eq/kg milk compared with the global average of 2.7 kg CO_2-eq/kg milk. The main reasons for the high level of emission intensities are the following:

- **Poor feed quality** (low feed digestibility) – leading to high enteric CH_4 emissions and low animal production performance. The average feed digestibility in the region is relatively low, estimated at 54 percent. Feeding systems are mainly based on crop residues such as straw and stover (making up 60 percent of the feed ration), green and dry fodder (34 percent), and by-products (almost 6 percent). Less digestible feed generates more CH_4 emissions per unit of energy ingested. Poor feed also affects animal productivity: milk yields are low (at about 965 kg per cow per year, compared with a global average of 2 269 kg per cow per year in dairy cattle mixed systems) and animals grow slowly, leading to older ages at first calving.
- **The importance of the "breeding overhead"** – animals contributing to emissions but not to production leading to higher emission intensities. The region is characterized by an important breeding overhead: about 57 percent of the dairy herd in South Asia is composed of non-milk producing animals compared with a global average of 41 percent in dairy cattle mixed systems.[22] This is caused by older age at first calving (3.1 year compared with a global average of 2.4 in mixed systems), in turn influenced by poor herd fertility and health (indicating that more animals are kept in the herd while producing no output) and the fact that male calves are not used for production in parts of the region.
- **High mortality rates** – leading to the loss of animals and therefore to "unproductive emissions" (death rates of 31.1 and 8.1 percent for calves and other animals respectively, compared with a global average of 17.8 and 6.7 in dairy cattle mixed systems).

Mitigation interventions explored

Considering the main drivers of emission intensity, this case study explored the mitigation potential offered by the following selected interventions:

- **Feed quality improvement.** Improving the digestibility of the diet, through feed processing or addition of locally available im-

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[21] South Asia comprises Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan and Sri Lanka.

[22] Non-milk producing animals defined here as animals kept for reproduction and replacement, including adult males and replacement females and males.

TABLE 11. Mitigation estimates computed for mixed dairy cattle systems of South Asia

Options	Mitigation effect compared with baseline
Total mitigation potential *(Million tonnes CO_2-eq)*	**120**
	(percentage)
Relative to baseline	**38.0**
...of which:	
Improved feeding	30.4
Improved herd structure	7.6

proved forages, results in better lactation performance (i.e. higher milk yields and animal growth) and reduced CH_4 emissions.[23]

- **Health and husbandry improvement.** The relative share of productive cohorts in the herd can be increased through improvements in animal health and reproduction management. The case study also explored, but for India only, the mitigation potential of a reduction of male calf cohorts (achieved by semen sexing in artificial insemination).

The mitigation potential of the first two interventions was calculated by modifying parameters related to feed quality and animal performance (growth rates, age at first calving, fertility rates and mortality rates) in GLEAM (Technical note 1).

Estimated mitigation potential

With feasible improvements in feed quality, animal health and husbandry, emissions can potentially be reduced by 38 percent of the baseline GHG emissions or 120 million tonnes CO_2-eq (see Table 11).

Diet improvement through improved digestibility has the highest mitigation potential, owing to its large impact on several sources of emissions. Notably, the mitigation largely results from a reduction in animal numbers: yield gains allow the same milk production to be achieved with 10 percent fewer animals (the reduction reaches 20 percent within breeding cohorts, as a result of improving herd structure).

Taking India as an example, the mitigation effect of improved feeding amounts to 85 million tonnes CO_2-eq, which accounts for 71 percent of the total mitigation effect for the South Asia region. The adoption of semen sexing technology for 25 percent of the dairy cows in India was estimated to reduce male calf numbers by 9 percent.

6.2 INTENSIVE PIG PRODUCTION IN EAST AND SOUTHEAST ASIA

Main characteristics

Production

East and Southeast Asia account for 50 percent of global pork production.[24] The People's Republic of China alone accounts for 40 percent. In the past three decades, pig production has increased fourfold in East and Southeast Asia. This growth has happened mostly in the People's Republic of China and in intermediate and industrial systems which now account for about 30 percent and 40 percent of the pig production in the region, respectively. These systems will continue to grow as production in this area is expected to further expand and intensify (FAO, 2011b).

Emissions

Intermediate and industrial systems in the region emit significant amounts of GHG, estimated at 320 million tonnes CO_2-eq per annum, representing 5 percent of the total global livestock sector emis-

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[23] Improved feeding is considered by many to be one of the most effective ways of mitigating enteric CH_4 emissions (see for example: FAO, 2013c; Beauchemin *et al.,* 2008; Monteny and Chadwick, 2006; Boadi *et al.,* 2004).

[24] East and Southeast Asia includes the People's Republic of China, Mongolia, Japan, Republic of Korea, Democratic People's Republic of Korea, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste and Viet Nam.

Credit: ©FAO/Simon Maina

sions. The regional averages of emission intensity (6.7 and 6.0 kg CO_2-eq/kg CW for intermediate and industrial pig production systems, respectively) are close to the global average levels, given the region's massive share of global pig production.

The main sources of emissions are:

- **Feed production,** which alone represents about 60 percent of total emissions from commercial systems. About half of these emissions are related to energy used for feed production (field operations, transport and processing and fertilizer production). Emissions of N_2O (from manure or synthetic N application to feed crops) account for about 28 percent of total feed emissions. Carbon dioxide from land-use change (related to imported soybean) is responsible for 13 percent of total emissions in industrial systems and 8 percent in intermediate systems. Methane emissions from rice in intermediate systems are also particularly high in the region, with 13 percent of total emissions.
- **Manure** is an important source of CH_4 emissions. In East and Southeast Asia, CH_4 emissions from manure account for 14 percent of total emissions in industrial systems and 21 percent in intermediate systems, due to both storage in liquid forms and the warm climates found in parts of the region. The average CH_4 conversion factor (i.e. part of organic matter actually converted to CH_4) in the region is 32 percent in intermediate and industrial systems, whereas the world averages are 27 percent in intermediate systems and 23 percent in industrial systems.
- **On-farm energy use and postfarm activities.** Direct energy used on-farm contributes more to emission intensity in industrial systems of the region (6 percent) than the world average (4 percent) for industrial systems. It is negligible in intermediate systems (about 1 percent). Postfarm emissions contribute about 8 percent to total emissions in both systems in the region.
- **Intermediate systems have a higher emission intensity compared with industrial systems.** This is due to lower animal and herd performance. In particular, late age at first farrowing (1.25 year in the region) and weaning age (40 days) result in a greater breeding overhead, which contributes to emissions but not to production. High mortality rates result in further "unproductive emissions". A lower feed quality results in lower daily weight gain (0.66 kg/day) leading to longer production cycles, thus increasing the relative part of energy (therefore emissions) dedicated to animal maintenance compared with production.

1 TECHNICAL NOTE

MODELLING MITIGATION OPTIONS FOR MIXED DAIRY PRODUCTION IN SOUTH ASIA

Feed quality improvement

Improved feeding can be achieved through the use of digestibility enhancing techniques such as feed processing (urea treatment, drying, grinding and pelleting) and use of improved forages such as mixes including legumes. It can also be achieved by supplementation of the base diet with by-products and concentrates. In this case study, the latter was limited to locally-available materials, thus assuming no impact of the mitigation scenario on feed trade.

The adoption of improved feed quality was modelled as follows in GLEAM (see Table A).

- In each pixel (smallest production unit in GLEAM), the baseline feed digestibility value was replaced by the value of the 10 percent pixels having the highest digestibility in the climatic zone (i.e. value of the 90th percentile in each agro-ecological zone).
- The age at first calving was computed assuming that a 1 percent increase in digestibility results in a 4 percent decrease in age at first calving. This assumption is derived from the relation between the digestibility of feed and the growth rate of animals (Keady *et al.*, 2012; Steen, 1987; Manninen *et al.*, 2011; Scollan *et al.*, 2001; Bertelsen *et al.*, 1993), and the assumption that growth rate and age at first calving go together.
- Milk yields were recalculated assuming that a 1 percent increase in the ration's digestibility would stimulate an increase in milk yield of 5 percentage points (Keady *et al.*, 2012; Manninen *et al.*, 2011; Scollan *et al.*, 2001; Bertelsen *et al.*, 1993).

Health and husbandry improvements

Increasing the share of the productive cohort within the herd can be achieved through reproduction management (reduced age at first calving and replacement rate of milking cows), better animal health (reducing mortality) and reducing the cohort of male calves using sexed semen in areas where male calves are not used for production purposes.

The adoption of improved reproduction management and health practices was modelled as follows in GLEAM (see Table A):

- Replacement rates and mortality rates were aligned to those of mixed farming systems in East Asia.
- Female-to-male sex ratio of calves was modified in India, from 50:50 in baseline to 80:20. This is based on the assumption that 50 percent of the farms use AI (after NDDB, 2013); 25 percent of these farms use sexed semen; and that where sexed semen is used, the female-to-male sex ratio of calves is shifted to 80:20 (Rath and Johnson, 2008, DeJarnette *et al.*, 2009; Norman *et al.*, 2010; Borchensen and Peacock, 2009).

Mitigation interventions explored

Considering the main sources of emissions from intermediate and industrial systems, this case study explored the following mitigation interventions:

- **Improvement of manure management.** The wider use of anaerobic digestion to lower CH_4 emissions and increase biogas production, which can also substitute for fossil fuels.
- **Adoption of more energy efficient technologies and low carbon energy.** This will reduce energy emissions related to feed production, farm management and postfarm activities.
- **Improvement of feed quality, animal health and animal husbandry in intermediate systems.** Higher quality and digestibility of feed results in reduced manure emissions and

TABLE A. GLEAM parameters modified to evaluate the mitigation potential for mixed dairy systems in South Asia

GLEAM parameters	Baseline	Mitigation scenario	Notes
Feed module			
Average digestibility of feed fed to milking cows *(percentage)*	arid: 54.8 (6.4)[1] humid: 53.3 (7.8)[1] temperate: 55.6 (6.4)[1]	arid: 63.4 humid: 62.7 temperate: 59.4	Feed digestibility value of 90th percentile[2] in each climatic zone – see text.
Herd module			
Replacement rate of milking cows *(percentage)*	21.0	18.0	Aligned to average value in GLEAM for mixed systems in East Asia.
Mortality rates *(percentage)*	female calves: 22.0 male calves: 52.0[3] other cohorts: 8.0	female calves: 17.0 male calves: 47.0[3] other cohorts: 7.0	Aligned to average value in GLEAM for mixed systems in East Asia.
Age at first calving *(year)*	3.1	2.5 to 2.9	Assumed 1 percent increase in digestibility will result in 4 percent decrease in age at first calving – see text.
Female-to-male calves sex ratio	50:50	80:20	Semen sexing technology applied to 25 percent of dairy cows in India only.
System module			
Milk yield	200 to 1 500 kg	200 to 3 587 kg	Assumed 1 percent increase in feed digestibility will increase milk yield by 5 percent – see text.

[1] Average digestibility and standard deviation.

[2] The value of feed digestibility under which 90 percent of the pixels can be found.

[3] Applies only to India.

better animal performance, through higher growth rates. Improved animal health management and animal husbandry lead to lower age at first farrowing and weaning, and also decreases death rates, increasing the share of producing animals in the herd.

The mitigation potential was calculated by modifying parameters related to manure management, energy use, feed quality and animal performance in GLEAM. The mitigation potential was calculated for both a modest business as usual (BAU) scenario and a more ambitious alternative policy scenario (APS) scenario, regarding the emissions from the use of energy (Technical note 2).

2

TECHNICAL NOTE

MODELLING MITIGATION OPTIONS FOR INTENSIVE PIG PRODUCTION IN EAST AND SOUTHEAST ASIA

Improvement of manure management

Designed to treat liquid manure, anaerobic digesters are one of the most promising practices for mitigating CH_4 emissions from manure (Safley and Westerman, 1994; Masse *et al.*, 2003a,b). When correctly operated, anaerobic digesters are also a source of renewable energy in the form of biogas, which is 60 to 80 percent CH_4, depending on the substrate and operational conditions (Roos *et al.*, 2004). The improvement of manure management was modelled as follows in GLEAM: the amount of manure treated in liquid form or drylots was decreased and the amount of manure treated in anaerobic digestion was increased to 60 percent (Table A). For Thailand, it was increased to 70 percent, from a baseline of 15 percent. The biogas produced by anaerobic digestion of manure was estimated and the equivalent CO_2 emissions saved from fossil fuel substitution calculated (under both energy efficiency improvement scenarios).

Adoption of more energy efficient technologies and low carbon energy

Kimura (2012) examined two potential energy trends in the region up to 2035. The first – BAU – reflects each country's current goals and action plans, and the second – APS – includes additional, more voluntary goals and action plans currently under consideration in each country. A partial shift from coal and oil to renewable energy and nuclear sources and the adoption of clean coal technologies and carbon capture and storage can reduce emissions from energy by 8 percent under the BAU scenario and 19 percent under the APS scenario.

Given that 85 to 95 percent of emissions from energy use in pig supply chains occurs off-farm in the region (fertilizer and food industries, transport of feed and products, etc.), it was assumed that the energy use efficiency achieved on an economy-wide level applies also to livestock production (15 and 32 percent under the BAU and APS scenario, respectively).

The improvement of energy use efficiency and the emission intensity of energy were modelled in GLEAM by reducing energy emission intensity by 23 percent under the BAU scenario and 46 percent under the APS scenario, in line with Kimura (2012).

Improvement of feed quality, animal health and animal husbandry in intermediate systems

Increasing the share of high quality ingredients (e.g. grains, oilseed cakes, minerals, additives) in the feed basket improves digestibility and animal performance. It reduces manure emissions because less N and organic matter are found in faeces per unit of meat produced. Health measures contribute to reducing mortality rates and increase age at first farrowing and weaning age. Globally, this will also decrease emission intensity as production is increased.

The adoption of improved feed quality was modelled as follows in GLEAM:

- the baseline feed digestibility value of intermediate systems was replaced with the value of the 10 percent pixels having the highest digestibility in intermediate systems of the region (i.e. value of the 90th percentile);
- the parameters of animal performance (daily weight gain, weaning age, age at first farrowing and death rates) were aligned to the average values in GLEAM between intermediate and industrial systems at the national level.

It was assumed that improved feed digestibility would be achieved by the partial replacement of rice products by maize (predominant in the feed basket of the 90th percentile). Given the high emission intensity of rice, this would lead to a reduced feed emission intensity. However, the replacement could, on the contrary, increase the feed emission intensity: a higher demand for maize could, indeed, lead to the expansion of agricultural land and thus higher feed emission intensity. Addressing this matter would require engaging in consequential analysis, in particular, to predict supply responses and changes in trade flows caused by the change in feeding practices. The uncertainties related to this kind of estimate are substantial and can hardly be determined on a global scale. Such an undertaking is also outside the scope of this assessment. The mitigation potential was, however, recalculated with a higher emission intensity: using an emission intensity of 0.9 kg CO_2-eq/kg DM (instead of 0.79 kg CO_2-eq/kg DM) would result in a mitigation potential of 24 percent of baseline emissions under the BAU energy scenario, and 30 percent under the APS scenario.

TABLE A. GLEAM parameters modified to evaluate the mitigation potential for intensive pig production in East and Southeast Asia

GLEAM parameters	Baseline	Mitigation scenario		Notes
Manure module				
Manure treated in anaerobic digesters *(percentage)*	7.0 (15.0 in Thailand)	60.0		
Feed module				
Feed digestibility *(percentage)*	76.0	78.0		Feed digestibility value of 90th percentile of intermediate systems.
Feed N content *(g N/kg DM))*	31.8	33.8		
Feed available energy *(kJ/kg DM)*	18.7	19.8		
Feed digestible energy *(kJ/kg DM)*	14.3	14.8		
Feed metabolizable energy *(kg CO_2-eq/kg DM)*	13.8	14.2		
Feed emission intensity *(kg CO_2-eq/kg DM)*	0.89	0.79		
Herd module[1]	**East and Southeast Asia**	**East Asia**	**Southeast Asia**	
Daily weight gain *(kg/day/animal)*	0.48	0.53	0.58	Aligned to average value in GLEAM between intermediate and industrial systems, at national level.
Weaning age *(days)*	40.0	32.5	37.0	
Age at first farrowing *(years)*	1.25	1.13	1.13	
Death rate of adult animals *(percentage)*	3.0	4.3	4.3	
Death rate of piglets *(percentage)*	15.0	13.0	13.0	
Death rate of replacement animals *(percentage)*	4.0	3.5	3.5	
Death rate of fattening animals *(percentage)*	2.0	3.5	3.5	
System module		**BAU**	**APS**	
Reduction in emissions from energy used to produce feed *(percentage)*	NA	- 23	- 46	Based on Kimura (2012).
Onfarm direct and indirect energy use		**BAU**	**APS**	
Change in energy emission intensity *(percentage)*		- 23	- 46	Based on Kimura (2012).
Postfarm emissions		**BAU**	**APS**	
Change in energy emission intensity *(percentage)*	NA	- 23	- 46	Based on Kimura (2012).

[1] Only for intermediate systems.

NA = Not applicable.

TABLE 12. Mitigation estimates computed for intermediate and industrial pig production in East and Southeast Asia

Farming system	**Intermediate pigs**		**Industrial pigs**		**Total commercial pigs**	
Energy scenario	BAU	APS	BAU	APS	BAU	APS
Total mitigation potential (*Million tonnes CO_2-eq*)	32	37	21	33	52	71
			(percentage)			
Share of baseline emissions	**31.5**	**37.6**	**15.5**	**24.9**	**27.7**	**36.0**
... of which:						
Reduced CH_4 from manure	9.2	9.2	4.2	4.2	6.1	6.1
Energy produced by biogas	2.2	1.9	1.7	1.4	2.3	1.9
Energy-use efficiency	4.9	9.8	9.6	19.3	9.9	19.0
Feed quality & animal performance[1]	15.2	16.7	NA	NA	9.4	9.0

[1] Only for intermediate systems.

NA = Not applicable.

Estimated mitigation potential

With feasible improvements in manure management and the adoption of more efficient technologies and low carbon energy, emissions in industrial systems could be reduced by 16 to 25 percent of baseline emissions, i.e. 21 to 33 million tonnes CO_2-eq (Table 12). The use of more energy efficient technologies can potentially lead to a reduction of emissions by about 9.6 to 19.3 percent. It is the most effective intervention to reduce emissions in industrial systems. The improvement of manure management offers a more modest reduction of 4.2 percent.

In intermediate systems, where the options of improved herd management and feed were also tested, emissions could be reduced by 32 to 38 percent of baseline emissions (32 to 37 million tonnes CO_2-eq). About half of the mitigation is achieved by improving feed quality and animal performance. Reduction in CH_4 emissions from improved manure management can potentially reach 9.2 percent of baseline emissions, making this option more effective for intermediate than for industrial systems.

When the energy production from biogas is added, mitigation ranges from 5.9 percent in industrial systems to 11.4 percent in intermediate systems under the BAU energy scenario. Mitigation is slightly reduced under the APS scenario and ranges from 5.6 percent to 11.1. Despite the relatively ambitious adoption rate assumed, mitigation achieved by energy recovery appears limited in this case study.

6.3 SPECIALIZED BEEF PRODUCTION IN SOUTH AMERICA

Main characteristics

Production

The South American[25] specialized beef sector[26] produces 31 percent of the meat from the global specialized beef sector and 17 percent of global production of cattle meat from both specialized beef and dairy herds.

Emissions

South American specialized beef emits about 1 billion tonnes CO_2-eq of GHG per year contributing 54 percent to emissions from global specialized beef production and 15 percent to emissions from the entire global livestock sector.

The emissions of the South American specialized beef sector mainly arise from the following three sources: enteric fermentation (30 percent); feed production, primarily from manure deposited on pasture (23 percent); and land-use change (40 percent).

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[25] Includes the following countries: Argentina, Bolivia, Brazil, Chile, Columbia, Ecuador, Guyana, Paraguay, Peru, Uruguay and Venezuela.

[26] This includes cattle herds that are used solely for the production of meat, i.e. it does not include meat that is derived from dairy herds.

The emission intensities of the South American and global specialized beef production supply chains are 100 kg CO_2-eq/kg CW and 68 kg CO_2-eq/kg CW, respectively. The main reasons for the high level of emission intensities are outlined below:

- **Land-use change.** The relatively high intensity of the sector in South America stems mostly from emissions related to land-use change. If emissions derived from land-use change are excluded, the average emission intensity for the sector in South America falls to 60 kg CO_2-eq/kg, only 9 percent higher than the global average of 55 kg CO_2-eq/kg. Land-use change emissions are higher in this region due to deforestation caused by the expansion of grazing lands.[27]
- **Feed emissions related to the deposition of manure on grasslands.** Excluding land-use change emissions, the remaining difference in the emission intensities can be explained by the higher feed N_2O emissions in South America; the emission intensity of feed N_2O from specialized beef is 33 percent higher in South America than for the globe as a whole (23 kg CO_2-eq/kg vs. 17 kg CO_2-eq/kg). This is because beef in South America is largely pasture-based, animals grow relatively slowly and manure deposited on pasture is prone to N_2O formation.
- **A larger breeding overhead.** Since the breeding herd is responsible for a disproportionately large share of emissions, but very little production, it contributes much more to enteric CH_4 emissions than the rest of the herd. The size of the breeding overhead is linked to relatively low growth rates (0.34 kg/hd/day and 0.43 kg/hd/day for females and males, respectively, compared with global averages of 0.45 kg/hd/day and 0.57 kg/hd/day for females and males, respectively) and lower fertility rates (73 percent compared with a global average of 79 percent). Lower growth rates increase the age at first calving (more time needed for heifers to reach sexual maturity) and increase the time required for meat animals to reach slaughter weight. On the other hand, mortality rates and average diet digestibility in South America are similar to global averages.

Mitigation interventions explored

This case study explored the mitigation potential of the following selected interventions:

- **Pasture quality improvement.** The sowing of better quality pasture and better pasture management can lead to improvements in forage digestibility and nutrient quality. This results in faster animal growth rates and earlier age at first calving. Better nutrition can also increase cow fertility rates, and reduce mortality rates of calves and mature animals, thus improving animal and herd performance (FAO, 2013c).
- **Improved animal health and husbandry.** Preventive health measures such as vaccinations to control disease and stress reduction (provision of shade and water) are also considered to play a role in reducing mortality rates and increasing growth and fertility rates, thus improving animal and herd performance.
- **Intensive grazing management (soil carbon sequestration).** The impact of better grazing management (improved balance between forage growth/availability and grazing) on promoting forage production and soil carbon sequestration is also assessed.

The mitigation potential of the first two options was calculated by modifying parameters related to feed quality and animal performance (growth rates, age at first calving, fertility rates, mortality rates) in GLEAM, whereas the third option was assessed using the Century model. The mitigation potential was calculated for two scenarios: one with modest and another with more optimistic assumptions about the effectiveness of the mitigation options (Technical note 3).

Estimated mitigation potential

With feasible improvements in forage quality, animal health and husbandry and carbon sequestration, emissions could be reduced by 18 to 29 percent of baseline emissions, or 190 to 310 million tonnes CO_2-eq (Table 13).

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[27] See discussion in FAO, 2013a.

3 TECHNICAL NOTE

MODELLING MITIGATION OPTIONS FOR SPECIALIZED BEEF PRODUCTION IN SOUTH AMERICA

Pasture quality improvement (digestibility, growth rates and age at first calving)

The digestibility of grasses can be improved though practices that reduce cell-wall concentration (Jung and Allen, 1995), including the sowing of better quality pastures and better pasture management (FAO, 2013c; Alcock and Hegarty, 2006; Wilson and Minson, 1980). According to Thornton and Herrero (2010), the replacement of native Cerrado grasses with more digestible Brachiaria decumbens has been estimated to increase daily growth rates in beef animals by 170 percent.

The improvements to forage quality were modeled as follows in GLEAM:

- Total diet digestibility was assumed to increase by between 1 and 3 percent.
- Growth rates were calculated assuming that every 1 percent increase in diet digestibility leads to a 4 percent increase of the average annual growth rate of the beef animals (Keady *et al.,* 2012; Steen, 1987; Manninen *et al.,* 2011; Scollan *et al.,* 2001; Bertelsen *et al.,* 1993).

Animal health and husbandry improvements (fertility and mortality rates)

In developing countries, inadequate nutrition is the primary factor limiting fertility in ruminant animals (FAO, 2013c); thus, the aforementioned improvements in feed quality will help improve fertility. In addition to nutrition, stress reduction (by improving access to shade and water), and preventive health measures such as vaccinations to reduce disease infection rates are also considered to play a role in lowering mortality rates and increasing fertility rates. The combined effect of improvements in feed digestibility, animal health and husbandry are characterized by the following adjustments to the animal and herd performance parameters in GLEAM:

- Fertility rates of adult females are increased from average rates of between 69 and 74 percent to between 85 and 90 percent. The upper bound in each climatic zone is based on personnel communication with a regional animal production expert (Diaz, 2013).
- A range of mortality rate improvements was also used. The upper bound improvements in the mortality rates shown in Table A are based on the best observed country average rates in GLEAM within the Latin America and the Caribbean, region, whereas the lower bound rates of improvement are calculated as the average between these best observed rates and the baseline rates. They represent what can be achieved under more conservative assumptions about the efficacy of the mitigation options.

Improved grazing management (soil carbon sequestration)

Estimates of soil carbon sequestration in grasslands come from an FAO study (Chapter 2 and Appendix), which uses the Century model to estimate the soil carbon sequestration potential for the world's grasslands. The per hectare sequestration rates, relevant to the specialized beef herd in the grazing lands of South America, were taken from this Century assessment (Table A).

The approach used in the Century assessment was to adjust grazing intensities both upwards and downwards, to better match grassland forage resources and, therefore, enhance forage production. By enhancing forage production, more organic matter is returned to soils, which, in turn, increase the amount of organic carbon stored in the soil (Conant *et al.,* 2001). The Appendix contains more details.

TABLE A. GLEAM parameters modified to evaluate the mitigation potential for specialized beef production in South America

GLEAM parameters	Baseline	Mitigation scenario	Notes
Feed module			
Feed quality	*(percentage)*		
Feed digestibility – temperate	57.0	58.0 to 60.0	1 to 3 percent increase assumed in each AEZ. See description of options to achieve this in text.
Feed digestibility – humid	63.0	64.0 to 66.0	
Feed digestibility – arid	63.0	64.0 to 66.0	
Herd module			
Animal performance – linked to feed quality			
Daily weight gain	*(kg/day/animal)*		
Female – temperate	0.31	0.32 to 0.35	
Male – temperate	0.40	0.42 to 0.45	
Female – humid	0.33	0.34 to 0.37	
Male – humid	0.42	0.44 to 0.47	
Female – arid	0.38	0.39 to 0.42	
Male – arid	0.48	0.50 to 0.54	
Age at first calving	*(years)*		
Temperate	3.5	3.3 to 3.0	Growth rate link with digestibility from literature. See description in text.
Humid	3.4	3.2 to 2.9	
Arid	3.1	3.0 to 2.7	
Animal performances - fertility & mortality	*(percentage)*		
Adult female fertility rate – temperate	69.0	80.0 to 90.0	Maximum based on expert knowledge (Diaz, 2013). Lower range is midpoint between maximum and observed.
Adult female fertility rate – humid	73.0	79.0 to 85.0	
Adult female fertility rate – arid	74.0	79.0 to 85.0	
Death rate of adult animals – temperate	19.0	13.0 to 8.0	Minimum based on the best country average rate in Central America. Upper range is midpoint between maximum and observed.
Death rate of adult animals – humid	15.0	11.0 to 8.0	
Death rate of adult animals – arid	14.0	11.0 to 8.0	
Death rate of calves – temperate	9.0	6.0 to 2.0	Minimum based on the best country average rate in South America. Upper range is midpoint between maximum and observed.
Death rate of calves – humid	6.0	4.0 to 2.0	
Death rate of calves – arid	5.0	4.0 to 2.0	
Soil carbon sequestration	*(tonnes CO_2-eq/ha/yr)*[1]		
Temperate	0.00	0.04	Outputs from Century modeling analysis. Rates applied to 5.3, 73.1, and 71.4 million ha respectively for temperate, humid and arid AEZs.
Humid	0.00	0.12	
Arid	0.00	0.08	

[1] Not in GLEAM, cf. Chapter 2.

TABLE 13. Mitigation estimates computed for specialized beef production in South America

	Temperate	Humid	Arid	Total
Total mitigation potential *(Million tonnes CO_2-eq)*	9.2 to 13.0	156.0 to 255.0	24.0 to 42.0	190.0 to 310.0
	(percentage)			
Share of baseline emissions	**39.4 to 57.5**	**17.5 to 28.4**	**16.3 to 28.9**	**17.7 to 28.8**
... of which:				
Improved feed quality	4.4 to 10.0	3.6 to 8.9	3.5 to 8.9	3.6 to 9.0
Improved fertility	7.5 to 12.0	3.7 to 5.7	3.2 to 5.4	3.7 to 5.8
Reduced mortality	20.0 to 28.0	9.4 to 13.0	8.0 to 13.0	9.4 to 13.0
Soil C sequestration	7.5	0.8	1.6	1.0

In each climatic zone, reductions in the mortality rate contribute most to mitigation. Feed quality and fertility contribute similar shares, while soil carbon sequestration has a more moderate but still important impact, especially in the temperate climatic zone. Total annual sequestration of soil carbon, on about 80 million ha of grasslands, is estimated to be 11 million tonnes CO_2-eq per year. For comparison, the Brazilian Government is committed to a carbon sequestration target of 83–104 million tonnes CO_2-eq through the restoration of 15 million ha of degraded grassland, between 2010 and 2020, in its Low Carbon Agriculture (ABC) programme,[28] which translates to the annual sequestration of 8.3–10.4 million tonnes CO_2-eq. While this is very similar to the rate estimated in this study, the ABC programme activity is being applied to a smaller area and to the restoration of degraded grasslands, whereas this assessment is based on optimizing grazing intensity across all grasslands. The higher per ha sequestration rates in the ABC programme are, however, in line with the literature on carbon sequestration from the restoration of degraded grassland sites (Conant and Paustian, 2002).

The combined effects of the mitigation measures reduce the total number of animals in the herd by 25 percent (under the most optimistic scenario). Most of this is due to a reduction in the breeding overhead, which falls by 36 percent. Most significantly, the combined effect of higher growth and fertility rates, and lower mortality rates, reduces the required number of replacement females by 44 percent. With a more productive herd, fewer adult females are needed, and fewer female calves are needed as replacement animals. As a consequence, the percentage of slaughtered fattening animals that is female increases from 49 percent in the baseline to 65 percent.

6.4 SMALL RUMINANT PRODUCTION IN WEST AFRICA

Main characteristics

Production

The small ruminant sector of West Africa[29] produced 642 thousand tonnes of meat[30] in 2005, equal to 53 percent of total ruminant meat produced in West Africa. The sector also supplied 728 thousand tons of FPCM – about one-third of total milk produced in the region.

Due to their hardiness, small ruminants are well suited to the region, and they are an important and relatively low-risk source of food and income for vulnerable households (Kamuanga *et al.*, 2008). In the region, 40 to 78 percent of the income of rural inhabitants is derived from agriculture (Reardon, 1997).

Emissions

The emission intensity of small ruminant meat production in West Africa is 36 kg CO_2-eq/kg CW,

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[28] http://www.agricultura.gov.br/desenvolvimento-sustentavel/recuperacao-areas-degradadas

[29] The region of West Africa covers the following countries: Benin, Burkina Faso, Cape Verde, the Republic of Cote d'Ivoire, Gambia, Ghana, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Saint Helena, Ascension and Tristan da Cunha, Senegal, Sierre Leone and Togo.

[30] Expressed in terms of CW.

TABLE 14. Mitigation estimates computed for the small ruminant sector in West Africa

	Sheep	Goats	Total
Total mitigation potential *(Million tonnes CO_2-eq)*	**4.7 to 7.1**	**3.0 to 4.9**	**7.7 to 12.0**
		(percentage)	
Share of baseline emissions	**32.7 to 48.7**	**20.7 to 33.1**	**26.6 to 41.3**
... of which:			
Improved feed quality	4.7 to 12.0	5.4 to 13.0	5.0 to 13.0
Improved fertility	6.0 to 6.7	1.9 to 2.5	4.0 to 4.6
Improved mortality	11.0 to 19.0	5.0 to 9.2	7.9 to 14.0
Soil C sequestration	11.0	8.4	9.7

which is 55 percent higher than the global average of 23 kg CO_2-eq/kg CW. The emission intensity of small ruminant milk produced in West Africa is 8.2 kg CO_2-eq/kg FPCM, 30 percent higher than the global average of 6.8 kg CO_2-eq/kg FPCM. The emission intensity levels can be explained by low herd productivity, caused by poor animal health and nutrition:

- **Poor feed quality (low feed digestibility).** Small ruminants in West Africa have an average feed digestibility of 55 percent compared with the global average of 59 percent. Low digestibility leads to higher digestive CH_4 emissions. Consequently, West Africa has higher enteric CH_4 emission intensities for small ruminant meat: 25 kg CO_2-eq/kg CW compared with the world average of 13 kg CO_2-eq/kg CW.
- **Poor animal health.** Poor feed quality and animal health combined lower the productivity of small ruminant herds through their negative impacts on growth, fertility and mortality rates: the growth rates for female and male animals are 0.04 kg/hd/day and 0.05 kg/hd/day, respectively, in West Africa, compared with the global average rates of 0.07 kg/hd/day and 0.09 kg/hd/day, respectively; the fertility rate in West Africa is 82.6 percent compared with the global average of 84.3 percent; and mortality rates for adult and young animals are 9.5 percent and 26.0 percent, respectively, in West Africa, compared with the global average rates of 8.8 percent and 20.6 percent, respectively. The combination of lower growth and fertility rates, and higher mortality rates increases the size of the breeding overhead.

Mitigation interventions explored

The case study explored mitigation options which address the main causes of low animal and herd productivity:

- **Forage quality improvement.** Improvements in feed digestibility can be achieved through the processing of locally-available crop residues (e.g. treatment of straw with urea) and by the supplementation of diets with better quality green fodder such as multipurpose leguminous fodder trees, where available. Better feed digestibility leads to better animal and herd performance.
- **Improved animal health, husbandry and breeding.** Preventive health measures such as vaccinations to control disease, stress reduction (provision of shade and water), and low input breeding strategies contribute to reducing mortality rates and increasing fertility rates, thus improving animal and herd performance.
- **Improved grazing management (soil carbon sequestration).** The impact of better grazing management (increased mobility, and a better balance between grazing and rest periods) can have a positive impact on forage production and soil carbon sequestration.

The mitigation potential of the first two options was calculated by modifying parameters related to feed quality and animal performance (growth rates, milk yields, age at first calving, fertility rates, mortality rates) in GLEAM, whereas the third option was assessed using the Century model. As with the third

TECHNICAL NOTE

MODELLING MITIGATION OPTIONS FOR SMALL RUMINANT PRODUCTION IN WEST AFRICA

Forage quality improvements (digestibility, growth rates and milk yields)

The processing of locally-available crop residues and the supplementation of relatively good quality green fodder such as multipurpose leguminous fodder trees, where available, lead to improved feed digestibility (see, for example, Mohammad Saleem, 1998; Mekoya *et al.,* 2008; Oosting *et al.,* 2011). Urea treatment is a viable option for improving digestibility and nutritional value of crop residues such as straws, which comprise a large share (39 percent) of small ruminant rations. This approach can increase the digestibility of crop residues by approximately 10 percentage units (Walli, 2011).

The improvement of forage quality was modelled as follows in GLEAM:

- Diet digestibility was increased by between 1 and 3 percent.
- Growth rates were recalculated assuming that every 1 percent increase in diet digestibility leads to a 4 percent increase in the average annual growth rate of the animals (Keady *et al.,* 2012; Steen, 1987; Manninen *et al.,* 2011; Scollan *et al.,* 2001; Bertelsen *et al.,* 1993).
- It was assumed that a 1 percent increase in the ration's digestibility would stimulate an increase in milk yields of 4.5 percentage points (Keady *et al.,* 2012; Manninen *et al.,* 2011; Scollan *et al.,* 2001; Bertelsen *et al.,* 1993).

Improved animal health, husbandry and breeding improvements (fertility and mortality rates)

In developing countries, inadequate nutrition is the primary factor limiting fertility in ruminant animals (FAO, 2013c); thus, the aforementioned improvements in feed quality will help improve fertility. Low input breeding strategies, such as reducing inbreeding (Zi, 2003; Berman *et al.,* 2011), and sire mate selection from highly fertile animals to improve fertility (FAO, 2013c) are considered as longer-term options. Health of animals is affected by many aspects of the production system, in addition to nutrition, stress reduction (by improving access to shade and water), and preventive health measures such as vaccinations to reduce disease infection rates are also considered to play a role in lowering mortality rates and increasing fertility rates.

The combined effect of improvements in feed digestibility, animal health and husbandry was characterized by the following changes to the animal and herd performance parameters in GLEAM. Fertility rates and mortality rates of lambs/kids and mature animals were adjusted as follows: the upper bound improvements in the fertility rates shown in Table A were based on the best observed country average rates in GLEAM within the North African region for both sheep and goats, whereas the upper bound improvements in the mortality rates were based on the best observed country average rates in GLEAM within the West African and West Asian regions for sheep and goats, respectively. The lower bound rates of improvement, in all cases, were calculated as the average between these best observed rates and the baseline rates. They represent what can be achieved under more conservative assumptions about the efficacy of the mitigation options.

Improved grazing management (soil carbon sequestration)

Estimates of soil carbon sequestration in grasslands come from FAO study (Chapter 2 and Appendix), which uses the Century model to estimate the soil carbon sequestration potential for the world's grasslands. The per ha sequestration rates relevant to the small ruminant herd in the grazing lands of West Africa were taken from this Century assessment (Table A).

The approach used in the Century assessment was to adjust grazing intensities both upwards and downwards, to better match grassland forage resources and, therefore, enhance forage production. This can be implemented by increasing mobility, and by making adjustments to grazing and pasture resting periods. By enhancing forage production, more organic matter is returned to soils, which, in turn, increases the amount of organic carbon stored in the soil (Conant *et al.,* 2001). The Appendix contains more details.

TABLE A. Mitigation options evaluated for the small ruminant sector of West Africa

Mitigation option	Baseline	Mitigation scenario	Notes
Feed module			
Feed quality	*(percentage)*		
Feed digestibility (sheep)	54.0	55.0 to 57.0	1-3% increase assumed in each AEZ. See description of options to achieve this in text.
Feed digestibility (goat)	54.0	55.0 to 57.0	
Herd module			
Animal performance – linked to feed quality			
Daily weight gain	*(kg/day/animal)*		
Sheep (female)	0.054	0.057 to 0.062	Growth rate link with digestibility from literature. See description in text.
Sheep (male)	0.073	0.077 to 0.083	
Goats (female)	0.033	0.034 to 0.043	
Goats (male)	0.038	0.040 to 0.043	
Milk yield	*(kg/day/adult female)*		
Sheep	0.085	0.089 to 0.096	
Goat	0.135	0.141 to 0.153	
Age at first calving	*(years)*		
Sheep	1.42	1.35 to 1.23	
Goats	1.90	1.81 to 1.64	
Animal performances - fertility & mortality	*(percentage)*		
Adult female fertility rate (sheep)	78.0	83.0 to 88.0	Maximum values based on highest country average in North Africa. Lower range value is midpoint between maximum and observed value.
Adult female fertility rate (goats)	88.0	90.0 to 92.0	
Death rate of adult animals (sheep)	13.0	10.0 to 8.0	Minimum values for sheep and goats based on lowest country averages for West Africa and West Asia, respectively. Upper range values are midpoints between maximum and observed values.
Death rate of adult animals (goats)	7.0	5.0 to 4.0	
Death rate of lambs (sheep)	33.0	23.0 to 13.0	
Death rate of kids (goats)	21.0	18.0 to 16.0	
Soil carbon sequestration[1]	*(tonnes CO_2-eq/ha/yr)*		
	0.00	0.17	Outputs from Century modeling analysis. Rates applied to 16.4 million ha.

[1] Not in GLEAM, cf. Chapter 2.

case study, the mitigation potential was calculated for two scenarios: one with modest and another with more optimistic assumptions about the effectiveness of the mitigation options (Technical note 4).

Estimated mitigation potential

With feasible improvements in forage digestibility, animal health, husbandry and breeding, and carbon sequestration, emissions can potentially be reduced by 27 to 41 percent of total annual baseline emissions, or 7.7 to 12 million tonnes CO_2-eq (Table 14).

The mitigation potential for sheep is higher than for goats, because sheep have larger bridgeable gaps in fertility and mortality rates than goats, allowing the subsector greater room to improve animal and herd performance.

Lower mortality rates contribute the most to mitigation for sheep, whereas improved feed quality is most effective for goats. Soil carbon sequestration makes the third largest contribution for the small ruminant sector as a whole (considering the upper range of the mitigation potentials for the other practices), offsetting almost 10 percent of its total emissions.

As with all ruminant sectors, substantial resources are expended, and emissions generated, in maintaining a large overhead or stock of animals, particularly in the breeding segment of the herd. The combined effect of the mitigation interventions was estimated to reduce the stock of animals needed to support baseline output by one-third for sheep and by just over one-fifth for goats.

6.5 DAIRY PRODUCTION IN OECD COUNTRIES

Main characteristics

Production

While countries belonging to the OECD[31] account for only 20 percent of the global number of dairy cows, they produce a massive 73 percent of global milk production. In these countries, mixed systems dominate, accounting for 84 percent of milk production. Within the OECD, the European Union is responsible for 37 percent of milk production and North America for 22 percent. Driven by growing domestic and global demand for dairy products, milk production has been increasing in North America and in Oceania since the 1980s, but has remained stable in the European Union as a result of the quota policy implemented since then.

Mixed dairy systems are different within OECD countries, but most of them share high productivity levels and a capacity to adopt mitigations options. Given these similarities, the OECD countries are assessed as a group in this case study, although results are presented for some individual countries and regions within this group.

Emissions

The average emission intensity of mixed dairy production in OECD countries is lower than the world average (1.7 and 2.9 kg CO_2-eq/kg milk,[32] respectively). However mixed dairy systems in OECD countries still account for 391 million tonnes CO_2-eq, representing 28 percent of total emissions from global milk production, and 6 percent of total emissions from the global livestock sector. The main sources of emissions are:

- **Enteric fermentation.** In the form of CH_4, it is the main source of emissions and accounts for about 30 percent of total emissions from milk in mixed systems in Western Europe and North America, 42 percent in Eastern Europe, and 38 percent in Oceania. The main driver of enteric emissions is feed digestibility, which is already relatively high in OECD countries: 72, 77 and 73 percent in North America, Western Europe and Oceania, respectively, compared with a global average of 60 percent.
- **Manure.** Emissions from manure are particularly high in systems where cattle are confined

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[31] Includes Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Poland, Portugal, Slovakia, Spain, Sweden, the United Kingdom of Great Britain and Northern Ireland, Switzerland, Norway, Iceland, Chile, Mexico, Israel, Turkey, Japan, Republic of Korea, Australia, New Zealand, Canada and the United States of America.

[32] Fat and protein corrected milk.

and manure managed in liquid forms (e.g. slurry accumulated in deep lagoons), as in North America, where they account for 17 percent of total milk emissions for mixed systems. The world average for mixed systems is 4 percent. Emissions are lower in Europe and Oceania, where dairy cattle manure is not stored in lagoons but in pits or managed in solid forms or deposited on pastures during grazing.

- **Energy emissions related to feed production, farm and postfarm activities.** Emissions arising from energy use in mixed systems during feed production (field operations, feed transport and processing, and fertilizer production), account for about 15 percent of total emissions from milk in North America, Eastern and Western Europe. They make a minimal contribution in Oceania (4 percent). Emissions related to the use of energy on farms[33] for mixed systems are high in OECD countries (about 4 percent of total milk emissions against a global average of 2 percent for mixed systems) as a result of high levels of mechanization. Emissions resulting from postfarm activities (milk processing and transport) in mixed systems also contribute to a greater share of the sector's emissions in OECD countries, where processing of dairy products is far more developed: 15 percent in North America and Oceania and 11 percent in Western Europe, compared to the world average for mixed systems of 6 percent.

Mitigation interventions explored

Considering the main sources of emissions from mixed dairy systems in OECD countries, this case study explored the mitigation potential offered by the following selected interventions:

- **Use of dietary lipid supplementation.** The use of linseed oils or cotton seed oil, in rations for lactating cows leads to a reduction of enteric fermentation.
- **Manure management improvement.** The wider use of anaerobic digestion results in lower CH_4 emissions and generates biogas that can substitute other forms of energy.
- **Adoption of more energy efficient technologies and the use of low carbon energy.** This reduces energy-related emissions of feed production, farm management and postfarm activities.

The mitigation potential was calculated by modifying parameters related to manure management, energy use, feed quality and animal performance in GLEAM. The mitigation potential was also calculated for dietary lipids, under both modest and more ambitious assumptions about its effectiveness (Technical note 5).

Estimated mitigation potential

With feasible improvements in manure management, energy use, feed quality and animal performance, the emissions could be reduced by 14 to 17 percent of the baseline GHG emissions, and 4 to 5 percent of the milk sector's global emissions, i.e. 54 to 66 million tonnes CO_2-eq (Table 15).

The mitigation potential ranges from 11 to 14 percent in Western Europe and from 11 to 17 percent in Australia and New Zealand. It is higher in North America (25 to 28 percent) due to the greater potential of replacing manure lagoons with anaerobic digesters.

In Western Europe and for the OECD as a whole, a more efficient use of energy contributes the most to the reduction in emissions (about 5 percent).

In North America, the wider use of anaerobic digesters – the option with the highest mitigation potential – could lead to a 12.7 percent reduction in emissions.

In Oceania, most mitigation is from the use of dietary lipids (3 to 9 percent abatement potential) because baseline enteric emissions are higher. The use of dietary lipids has less impact in North America and Western Europe (1 to 4 percent), but in absolute terms its mitigation potential is not negligible: 1.5 to 4.4 million tonnes CO_2-eq

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[33] Energy directly used on farm and indirectly used for farm equipment and buildings.

in North America and 2.3 to 6.8 million tonnes CO_2-eq in Western Europe.

Biogas production contributes to reducing the emissions from energy by replacing fossil fuels. The mitigation potential ranges from 1 percent in Australia and New Zealand, where liquid manure storage is not frequent, to 4 percent in North America. The aggregated effect of CH_4 emission reduction and energy substitution ranges from 3.9 percent in Oceania to 17.1 percent in North America.[34]

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[34] These estimated mitigation potentials are in line with voluntary mitigation initiatives undertaken by the dairy sector. The Innovation Center for US Dairy announced that the sector aimed to reduce its emissions by 25 percent between 2009 and 2020 (Innovation Center for US Dairy, 2008). In Western Europe, the *Milk Roadmap* (2008) prepared by the UK Dairy Supply Chain Forum indicates intentions to cut emissions from dairy farming by 20 to 30 percent between 1990 and 2020, and improve the energy efficiency of the industry by 15 percent (1.3 percent/year).

5

TECHNICAL NOTE

MODELLING MITIGATION OPTIONS FOR DAIRY PRODUCTION IN OECD COUNTRIES

Use of dietary lipid supplementation

Among the various feed supplements that reduce enteric CH_4 emissions, lipids like linseed oil or cotton seed oil are increasingly mentioned as the most feasible, despite their cost (Beauchemin *et al.,* 2008). Dietary lipids, added to the ration of lactating cows in mixed systems in up to 8 percent of the diet in dry matter, can result in enteric CH_4 abatement of 10 to 30 percent (Nguyen, 2012, Grainger & Beauchemin, 2011; Rasmussen & Harrison, 2011). Although several meta-analyses of scientific experiments report a positive impact on productivity (Rabiee *et al.,* 2012; Chilliard and Ferlay, 2004), some dietary lipids have been reported as having a negative impact on dry matter intake and milk production (e.g. Martin *et al.,* 2008). In practice, supplementation is generally not provided to the entire lactating herd, but to the animals that have over average performances.

The use of feed additives was modelled in GLEAM by reducing the enteric CH_4 emissions of half of the lactating cows by 10 to 30 percent (Table A).

Improvement of manure management

Designed to treat liquid manure, anaerobic digesters are one of the most promising practices for mitigating CH_4 emissions from manure (Safley and Westerman, 1994; Masse *et al.,* 2003 a,b). Anaerobic digesters, when correctly operated, are also a source of renewable energy in the form of biogas, which is 60 to 80 percent CH_4, depending on the substrate and operation conditions (Roos *et al.,* 2004).

The improvement of manure management was modelled as follows in GLEAM:

- Sixty percent of manure treated in lagoons or pits and 25 percent of manure daily spread in baseline was assumed to be transferred to anaerobic digesters. As a result, the share of manure treated in anaerobic digestion ranges from 0 percent (where baseline manure management system does not include any liquid form (e.g. Greece, Turkey, Israel) to more than 40 percent, where liquid manure is important in the baseline (e.g. Germany, the Netherlands, Denmark and United States of America).
- The biogas produced by anaerobic digestion of manure was calculated and the equivalent CO_2 saved from energy generation was estimated.

Adoption of more energy efficient technologies and low carbon energy generation

Decreasing the emission intensity of energy requires decarbonizing power generation, which can be achieved through a significant switch to renewable energy production and wider carbon capture and storage (International Energy Agency (IEA), 2008). The IEA report (2008) examined energy development pathways in OECD countries up to 2050 and their impacts on GHG emissions. In the BLUE Map scenario

6.6 POTENTIAL FOR PRODUCTIVITY GAINS

Many mitigation options can concomitantly lead to a reduction of emission intensities and an increase in production. This is particularly the case with improved feed and feeding practices, and better health and herd management practices.

Rationale for holding output constant

For various reasons, production volumes were held constant while computing the mitigation scenarios in GLEAM. First of all, it permits clear comparison of mitigation effects across systems and practices. Secondly, because GLEAM is a static biophysical model which does not include economic supply and demand relationships for livestock commodities, any increases in production from the assessed mitigation practices would necessarily be arbitrary. The main reason is that increases in the supply of livestock commodities would depress their prices, and prompt a subsequent reduction

introduced by IEA (2008), emissions in 2050 are reduced by 50 percent compared with 2005 through reduction in energy emission intensity and gains in energy use efficiency in all economic sectors at the rate of 1.7 percent per year.

The improvement of energy efficiency and the decrease of emission intensity of energy were modelled in GLEAM by reducing emissions from energy by 15 percent, which corresponds to the situation in 2030.

TABLE A. GLEAM parameters modified to evaluate the mitigation potential for mixed dairy production in OECD countries

GLEAM parameters	Baseline	Mitigation scenario	Notes
	(percentage)		
System module			
Reduction in enteric CH_4 emissions	0	10 to 30	Nguyen (2012), Grainger & Beauchemin (2011), Rasmussen & Harrison (2011).
Percentage of milked cows (adoption rate)	0	50	
Emissions from energy used to produce feed	NA	-15	Based on IEA (2008) - BLUE map scenario.
Manure module			
Percentage of manure treated in anaerobic digesters	0[1]	Vary from 0 to 53	Partial transfer of liquid manure to digesters (60 percent of manure in lagoon and pits and 25 percent of manure daily spread).
Onfarm direct and indirect energy use	NA	- 15	Based on IEA (2008) - BLUE map scenario.
Emissions from energy			
Postfarm emissions			
Emissions from energy	NA	-15	Based on IEA (2008) - BLUE map scenario.

[1] Assumed to be zero given the low level of adoption.

NA = Not applicable.

TABLE 15. Mitigation estimates computed for mixed dairy systems in OECD countries

	OECD countries in North America	OECD countries in Western Europe	OECD countries in Oceania	All OECD countries
Total mitigation potential *(Million tonnes CO_2-eq)*	25 to 28	21 to 26	2 to 4	54 to 66
	(percentage)			
Share of baseline emissions	**24.8 to 27.7**	**11.2 to 13.6**	**11.2 to 17.4**	**13.8 to 16.8**
... of which:				
Fat supplementation	1.5 to 4.4	1.2 to 3.6	3.1 to 9.3	1.5 to 4.5
Manure management	12.7	2.8	3.2	4.9
Biogas production	4.4	2.4	0.7	2.4
Energy-use efficiency	6.2	4.8	4.2	5.0

in their supply by producers. In situations where the mitigation practices lower production costs, these negative feedback effects could possibly be offset or even reverted, leading to increased consumption. However, in the absence of a rigorous economic framework to estimate these important and complex market feedbacks, output was deliberately held constant.

Modelling changes to better understand the potential for both production increase and emission reduction

By holding production constant, the mitigation options based on productivity and feed quality improvements made it possible to deliver the baseline level of production with fewer animals, thereby reducing emission intensity.

When, in contrast, the mitigation interventions are tested while holding the number of adult female[35] animals constant, output is estimated to increase in four of the five case studies in which mitigation options improve animal performance (Table 16).[36] Naturally, when the GLEAM model is run under these settings, the absolute mitigation potentials are lower than when output is held constant. Nonetheless, under these settings, the mitigation options result in the simultaneous increase in output and reduction in emissions, in three of the four case studies.

In mixed dairy systems in South Asia, the selected mitigation options can lead to both a production increase of 24 percent and a reduction of emissions of 23 percent. In West Africa, selected mitigation options can result in an increase in meat and milk production by between 19 and 40 percent and 5 to 14 percent, respectively, while emissions can be reduced by 7 to 19 percent. In commercial pig production in Asia, the selected mitigation options lead to a 7 percent increase of production and concomitant emission reductions of 22 to 30 percent.

Ruminant sectors experience the largest increases in output and smallest reductions in emission, due to the importance of mitigation measures that boost animal productivity. By contrast, the commercial pig sector achieves marginal increase in output, but larger emission reductions due to the greater importance of energy efficiency and “end-of-pipe” mitigation practices in this case study.

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[35] This animal cohort is central to production and the only one available in FAOSTAT, together with total animal numbers.

[36] The mitigation options explored for mixed dairy production in OECD countries had no effect on productivity and overall production.

TABLE 16. Effect of maintaining animal numbers constant on the production and emission volumes estimated in four case studies*

	Mixed dairy systems in South Asia	Commercial pig production in East and Southeast Asia	Specialized beef production in South America	Small ruminant production in West Africa	
				Meat	Milk
Production *(Million tonnes FPCM or CW)*					
Baseline	56	50	10.7	0.64	0.73
Mitigation scenario	69	53	13.5 to 15.7	0.76 to 0.90	0.76 to 0.83
Change compared to baseline (percentage)	*+24*	*+7*	*+27 to +48*	*+19 to +40*	*+5 to +14*
Emissions *(Million tonnes CO_2-eq)*					
Baseline	319	234	1 063	29	
Mitigation for constant output	199	152 to 169	753 to 874	17 to 21	
Change compared to baseline (percentage)	*-38*	*-28 to -35*	*-29 to -18*	*-41 to -27*	
Mitigation with increased output	247	163 to 182	1 126 to 1 128	24 to 27	
Change compared to baseline (percentage)	*-23*	*-22 to -30*	*+6.0 to +5.8*	*-19 to -7*	
Emission intensity *(kg CO_2-eq/kg FPCM or CW)*					
Baseline	5.7	4.7	100	36	8.2
Mitigation scenario	3.6	3.0 to 3.4	72 to 83	22 to 29	5.3 to 6.8
Change compared to baseline (percentage)	*-38*	*-28 to -35*	*-28 to -16*	*-40 to -20*	*-35 to -17*

* Mitigation interventions explored in the four case studies are described above.

KEY MESSAGES OF CHAPTER 7

- The livestock sector should be part of any solution to climate change: its GHG emissions are substantial but can readily be reduced by mitigation interventions that serve both development and environmental objectives.

- There is a strong link between emission intensity and resource use efficiency. Most mitigation interventions will result in increased resource use efficiency along the sector's supply chains.

- Supportive policies, adequate institutional frameworks and more proactive governance are needed to fulfil the sector's mitigation potential and promote its sustainable development.

- Extension and capacity-building policies can facilitate the transfer and use of more efficient practices/technologies that are readily available. Financial incentives are important complementary policy tools, particularly for mitigation strategies that increase risks and costs to farmers.

- Research and development is vital for increasing the availability and affordability of effective mitigation options. Significant additional research is also needed to develop more accurate and affordable measurement methods, to demonstrate success through piloting and provide new technologies for mitigation.

- Practices/technologies that mitigate by improving production efficiency are key to mitigation interventions in least affluent countries, as they can minimize trade-offs between mitigation, food security and rural livelihoods.

- Efforts should be pursued to ensure that existing provisions and rules at regional, national and international levels, within and outside the UNFCCC, provide stronger incentives to mitigate livestock sector emissions and ensure that efforts are balanced through the different sectors of the economy.

- Recent years have seen interesting and promising initiatives by both the public and private sectors to mitigate the sector's emissions, and, more generally, to address sustainability issues.

- Due to the size and complexity of the global livestock sector, concerted and global action by all stakeholder groups (including producers, industry associations, academia, the public sector, intergovernmental organizations, and non-governmental organizations) is needed to design and implement cost-effective and equitable mitigation strategies and policies.

IMPLICATIONS FOR POLICY-MAKING

Livestock matters to climate change. The sector contributes 7.1 gigatonnes CO_2-eq to global anthropogenic GHG emissions – a contribution that can be readily reduced by up to one-third – placing the sector as an integral part of any solution to climate change.

Supportive policies, adequate institutional frameworks and more proactive governance are needed to fulfil the sector's mitigation potential, and promote its sustainable development.

Livestock plays a critical role in achieving food security, especially in harsh agro-environmental environments; however, its growth and the related use of natural resources are mostly driven by urban consumers in emerging economies. With demand for livestock products projected to grow by 70 percent by 2050, concerns about the unbalanced nature of this growth and its attendant environmental and socio-economic consequences are increasing. To date, most of the increase in demand has been met by rapidly growing, modern forms of production while hundreds of millions of pastoralists and smallholders, who depend on livestock for survival and income, have little access to emerging opportunities for growth. In addition, there is increasing concern about the impact of production growth on natural resources of which the sector is a large user; it is, for example, the world's largest user of agricultural land.

Policy-makers need to focus on mitigation strategies that serve both development and environmental objectives. Much of the mitigation potential in the sector is achievable by using available practices that improve production efficiency, which can reduce emissions while supporting social and economic goals such as food security and income generation; (Box 4 summarizes the main emission reduction strategies identified in this assessment). In turn, mitigation policies that focus on strategies that are able to deliver private benefits, are likely to enjoy greater success and uptake.

This chapter explores where the main available mitigation strategies can be used, and which policies could support their adoption. The role that existing policy frameworks at international and country levels currently play is also discussed, along with options for accelerating mitigation in the livestock sector.

7.1 A BRIEF DESCRIPTION OF MITIGATION POLICY APPROACHES

Mitigation policy approaches available to policy-makers are not unique to climate change or to livestock; they are broadly the same for most environmental management and development issues:

- *Extension and agricultural support services*: this suite of approaches facilitates practice

BOX 4. MAIN EMISSION REDUCTION STRATEGIES

While mitigation interventions will obviously need to be tailored to local objectives and conditions, broadly defined available mitigation options can be recommended for monogastrics and ruminants:

- Interventions for ruminant production:
    - *at animal level:* optimize feed digestibility and feed balancing, achieve better animal health, and improve performance through breeding.
    - *at herd level:* reduce the proportion of the animals in the herd dedicated to reproduction and not to production. This can be achieved by improving feeding, health and genetics (all having an effect on fertility, mortality and age at first calving), but also through herd management practices aimed at reducing age at first calving, adjusting slaughtering weights and ages, and adjusting replacement rates in the dairy herd.
    - *at production unit level:* In grazing systems: improve grazing and grassland management to increase feed quality and carbon sequestration. In mixed systems: improve the quality and utilization of crop residues and fodder, enhance manure management.
    - *at supply chain level:* increase the relative beef production supplied by herds producing both meat and milk, adopt energy efficient practices and equipment, encourage waste minimization along supply chains.
- Interventions for monogastric production:
    - *at animal level:* improve feed balancing, animal health and genetics to increase feed conversion ratios and reduce N and organic matter excreted per unit of product.
    - *at production unit level:* produce or source low emission intensity feed (reducing land-use change arising from feed production, improving crop fertilisation management as well as the efficiency of energy use in feed production and processing), adopt energy efficient practices and equipment, and enhance manure management.
    - *at supply chain level:* foster energy efficiency and use of low emission intensity energy, reduce waste generation along supply chains and increase recycling.

change for mitigation and development by providing access to improved practices/technologies, knowledge and capacity for their application, and information about emerging market opportunities. Commonly used approaches include communication, training, demonstration farms and networks to facilitate linkages among sector stakeholders.

- *Research and development*: research and development is necessary to build the evidence base for mitigation technologies/practices. It can play an important role in refining existing technologies/practices to increase their applicability and affordability, and is also necessary for increasing the supply of new and improved mitigation technologies/practices.
- *Financial incentives*: includes either ‘beneficiary pays’ mechanisms (abatement subsidies) or ‘polluter pays’ mechanisms (emissions tax, tradable permits). These are economically efficient mechanisms for incentivizing the adoption of mitigation technologies/practices.
- *Regulations*: includes assignment of mitigation targets for farmers/sectors, as well as more prescriptive approaches such as mandating the use of specific mitigation technologies and practices.

- *Market friction instruments*: includes instruments that seek to increase the flow of information about the emissions associated with different livestock commodities (e.g. labelling schemes). This can help consumers and producers to better align their consumption and production preferences with the emission profiles of these commodities.
- *Advocacy*: includes the raising of awareness about livestock's role in tackling climate change to influence and promote mitigation policy development for the sector (e.g. through intergovernmental representation of this issue in the UNFCCC negotiation process).

In line with the mitigation assessments in this report, this chapter focuses on policies to support supply-side mitigation options. While demand-side mitigation approaches that directly target consumers of livestock products are also important, they are considered not within the scope of this report.

7.2 TARGETING OF MITIGATION POLICIES

The potential to mitigate GHG emissions exists in all subsectors and regions. While more research is needed to better understand this mitigation potential, the emission profiles developed in this assessment provide a first indication of where mitigation policies might be targeted. For instance, policies may have the largest impact if they target sectors and regions where emission levels and emission intensities are the highest.

Subsectors with high emission intensities

Mitigation policies focusing on the high emitting ruminant sectors, particularly in least affluent countries, could have the highest impact. Emission profiles show that cattle alone account for two-thirds of the sector's emissions. When all ruminants are considered together, this share increases to 80 percent. At the global level, specialized beef meat production is most emission-intensive (67.8 kg CO_2-eq), followed by small ruminant meat (23.8 kg CO_2-eq) and dairy meat (18.4 kg CO_2-eq), and the emission intensities are consistently lower in most affluent countries. Monogastric production not only contributes a smaller share of total emissions, it is also much less emission intensive: the average emission intensities of chicken and pig meat are 5.4 kg CO_2-eq and 6.1 kg CO_2-eq, respectively.

Subsectors with high emission levels

Mitigation policies focusing on subsectors where emissions intensities are comparatively low but absolute levels of emissions are high would also be highly effective. In these situations, small additional reductions in emission intensity can still yield sizeable mitigation outcomes. This is, for example, the case for milk production in OECD countries and pork production in East Asia.

Hot spots along the supply chains

Policies targeting emission "hot spots" along the sector's supply chains would also likely be more effective. For example, the analysis highlighted the importance of emissions from energy consumption along the chains as an important source of emissions (about one-third of total emissions in pork supply chains). Incentives to increase the sourcing of low emission intensity energy and improve energy use efficiency could, therefore, be an effective mitigation option for this subsector.

The LCA approach, which makes it possible to trace emission sources related to all facets of livestock production, can help identify "hot spots" to customize and target policies accordingly.

Further analysis required on mitigation potential

Naturally, the presence of high emissions in a particular sector or region does not guarantee that mitigation policies targeting these sectors will be effective. Further technical analyses are needed to assess the potential for mitigating these emission sources.

The effectiveness of mitigation policies will also depend very much on barriers to adoption, particularly in the ruminant sectors of less affluent countries where much of the global mitigation potential is found. These barriers include investment and other adoption costs, capacity constraints and risk. In the following sections, these issues and their impact on policy design are discussed within the context of the main mitigation strategies identified in Chapter 6. Further research to overcome these barriers and identify mitigation strategies and policies that can deliver environmental, social and economic benefits will be essential to achieving the mitigation potential of the livestock sector modelled in this study.

7.3 MAIN MITIGATION STRATEGIES AND THEIR POLICY REQUIREMENTS

Closing the efficiency gap

GHG emissions represent losses of energy, nitrogen and organic matter for the livestock sector (Chapter 4). There is thus a strong link between emission intensity and resource use efficiency, and most mitigation interventions will result in increased resource use efficiency along the sector's supply chains.

As a result, the large mitigation potential that can be found in closing the gap between the producers with highest emission intensity and those with the lowest (Chapters 5 and 6) can be achieved by the transfer and use of existing technologies that increase production efficiency. Several types of policies can support the effective transfer of technologies and practices.

Policy requirements

Policies fostering knowledge transfer

Policies targeting knowledge transfer are particularly important for stimulating the adoption of efficient technologies and good management practices by farmers. For example, extension activities can be used to facilitate change in practices by providing access to knowledge and improved practices and technologies. These may include farm visits by extension agents, the establishment of demonstration farms, farmer field schools and farmer networks to promote peer-to-peer knowledge transfer, sector roundtables and the brokering of linkages among sector participants. Extension activities need a coherent and integrated approach to building sector capacity in order to ensure the successful application of existing and new mitigation practices. There is also a role for policies to create and enhance enabling conditions for the transfer of technologies, including infrastructure development and the strengthening of supporting technical institutions.

Enabling conditions for technology transfer and innovation

Generally, innovation is driven by entrepreneurs pursuing market opportunities (World Bank, 2006), and knowledge and technologies seem to work best when their introduction is complemented by infrastructure and institutional development, partnerships and policy support (IFPRI, 2009). Research and development can play an important supporting role by generating knowledge and evidence about technologies and practices, giving farmers and practitioners greater confidence about their mitigation effectiveness and production impacts. Pilot projects to test the effectiveness and feasibility of novel technologies and practices in different agro-ecological and socio-economic contexts are an important part of this strategy. So, too, are regulations and economic policies to direct research, development and the diffusion of new technologies along livestock supply chains.

Removing barriers to and creating incentives for efficiency improvement

Financial instruments, such as low interest loans and microfinance schemes, may be needed to complement extension policies and support the adoption of new technologies and practices. These instruments are required when practices require upfront investments and their adoption is constrained by ineffective or missing capital markets and financial services, which is a common constraint to technology use in developing country contexts. These types of instruments may therefore be required even where the mitigation options promoted are profitable and producers are willing to bear the costs related to technology transfer.

There may also be other barriers to adoption, including producer aversion to change and increased risks associated with adoption, as well as opportunity costs for adopting mitigation practices instead of other investments that farmers may be contemplating. These factors will increase the minimum rate of return producers would be willing to accept before investing in these mitigation practices and will require higher levels of support and incentives.

This may include subsidies to support the adoption of more efficient technologies and practices that may not be profitable for all farmers. Mitigation subsidies can be designed to cover part (e.g. cost-sharing mechanisms) or all of the mitigation costs incurred by farmers. Subsidy instruments may stand alone (i.e. funded by government), or they may be supplied through offset schemes where these mechanisms exist (e.g. the Clean Development Mechanism and the Carbon Farming Initiative in Australia).[37]

Policy-makers need to pay close attention to the constraints faced by farmers in differing socio-economic contexts. Livestock supply chains are heterogeneous and face differing adoption constraints and challenges. This is particularly true in developing countries where there is often a continuum of farmers ranging from those who operate in poorly functioning markets (for inputs, outputs, credit and land) whose main motivation is subsistence, to those who specialize in livestock and are integrated into more economically efficient markets. The transfer of practices and technologies through the use of extension and policy incentives is much more likely to be effective for the latter group than for subsistence farmers, who will often be unable to obtain the same economic returns from adoption (Jack, 2011). Mitigation policies must, therefore, be tailored to match the differing motivations and market contexts of farmers.

Additional research on costs and benefits of mitigation practices

Significant additional research is needed to further assess the costs and benefits of mitigation practices, to help policy-makers understand which policy options are better placed to incentivize their uptake.

Only a handful of GHG mitigation assessments have explored the economics of practices that improve production efficiency (including USEPA, 2006; Beach *et al.*, 2008; Moran *et al.*, 2010; Schulte *et al.*, 2012; Whittle *et al.*, 2013; Smith *et al.*, 2007; McKinsey, 2009; Alcock and Hegarty, 2011). While a significant share of these practices is estimated to be profitable, findings vary considerably, depending on which mitigation options are assessed and which species and regions they are applied to. For example, genetic alterations to beef and dairy cattle to improve production and fertility have been estimated to be profitable in the United Kingdom of Great Britain and Northern Ireland (Moran *et al.*, 2010), as have genetic improvements for beef cattle in Ireland (Schulte *et al.*, 2012), and breeding for higher ewe fecundity in some sheep enterprises in Australia (Alcock and Hegarty, 2011). Conversely, some feeding and grazing strategies for improving herd efficiency were estimated by USEPA (2006) to be profitable in some cases (e.g. intensive grazing for cattle in the United States of America and Brazil), but prohibitively expensive in others (e.g. concentration inclusion in dairy cattle diets in the People's Republic of China). More systemic research is needed to provide a more consistent understanding of the costs and benefits of these practices in different production contexts.

Policies required to address potential risks

Constraints on sector emissions

Policies to constrain sector emissions may be needed when efficiency improvements cause production to expand and thus induce higher emissions. For example, some efficiency enhanc-

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[37] While it is also possible to incentivize the adoption of mitigation practices with a financial penalty such as an emission tax (based on the 'polluter pays' principle), this is likely to be a politically unpopular policy approach which, to the authors' knowledge, has not been used to regulate agricultural GHG emissions before. Moreover, financial penalties would reduce farm incomes and increase food prices, and possibly exacerbate hunger and poverty in developing countries where emission intensities and, therefore, the financial penalties imposed by such policy instruments, would be the highest.

ing practices may create incentives for farms to increase their herd size, if doing so allows them to extract higher returns on their investments. Alcock and Hegarty (2011) argue that such incentives arise when ruminant producers invest in pasture improvement. The same issue is present on the industry scale, where mitigation practices that increase profits (either because the practices are themselves profitable or because incentive policies make them profitable), can attract new entrants to industries, increasing output and potentially also emissions (Perman *et al*., 2003). These mitigation options may, therefore, be more effective if countries choose to introduce supporting policies to constrain emissions in the sector (e.g. through tradable or non-tradable emission permits).

Regulations on land use clearance

Regulations to prevent land use clearing may be needed when efficiency improvements lead to production expansion and further land clearance for pasture or crop production. Improvements in production efficiency can have strong ramifications for land-use change, because they can lower the amount of inputs required, including land for grazing and feed production, to produce any given level of output. In this respect, farm efficiency improvements can be considered a necessary condition for preventing the conversion of forest land into agriculture land for livestock. But again, where efficiency improvements are profitable, it is possible that their adoption can lead to an expansion in production and land use. However, it is difficult to assess and anticipate the net direction of land-use change following such improvements (Lambin and Meyfroit, 2011; Hertel, 2012). Given this uncertainty, supporting regulations to prevent land use clearing would help to safeguard against cases where improvements in production efficiency might unexpectedly encourage deforestation.

Safeguards against potential negative side-effects

Production efficiency improvements can provide environmental co-benefits, in addition to GHG mitigation, by lowering the natural resource requirements of the livestock sector. However, policy safeguards ought to be used to avoid negative environmental (e.g. soil and water pollution from animal wastes), animal welfare and disease side-effects, where productivity improvements lead to land intensification (i.e. a move towards greater animal confinement and importation of higher energy feeds). One example of such a safeguard is the European Union's integrated pollution and control directive[38] which, among other things, requires producers to obtain a permit to establish piggeries with more than 750 breeding sows. This permit requires the producers to comply with environmental criteria such as treatment of waste, distance to settlements and water flows, and ammonia emissions. Ethical concerns about animal welfare may also introduce important trade-offs with measures to enhance production efficiency.

Loss of non-food goods and services

A single-minded focus on production efficiency can introduce trade-offs with other livestock services that are important in more traditional farming systems. Developing country farmers often keep some animals for non-food production functions, including risk mitigation, financial services, draught power and provision of manure for crops. Efficiency improvements that are based solely on saleable commodities could result in lower herd sizes in some cases, and thus reduce some of their ancillary services (Udo *et al*., 2011). Unless they are able to be cost-effectively substituted with mechanization, use of artificial fertilizers, and banking and insurance systems, these lost services would be detrimental to farm household livelihoods.

Grassland carbon sequestration

Grazing land and pasture management practices that increase soil carbon stocks can significantly mitigate CO_2 emissions and may present opportunities for profitable investment in mitigation.

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[38] Directive 2010/75/EU of the European Parliament and of the Council, 24 November 2010.

Recent global modelling work led by FAO estimates that an annual carbon sequestration potential of 409 million tonnes CO_2-eq is possible in just over one billion ha of the world's grassland area (Chapter 5). In 46 percent of this area, this can be achieved by increasing both grazing pressure and grass consumption. And in a further 31 percent of this area, reducing grazing pressure was shown to increase grass production and consumption. In addition to mitigating CO_2 emissions, these practices increase soil health and grass production and provide environmental co-benefits (e.g. biodiversity and water quality), particularly where the restoration of degraded grasslands is involved.

Further research

Further research is needed before this strategy can be supported on a large scale. While there is relatively abundant experimental and modelling evidence demonstrating the effectiveness of this strategy in some locations, there is a paucity of pilot projects and economic assessments which are needed to support the design of technical itineraries and to verify the long-term viability of this strategy. Concerns relate to the permanence of the sequestration of carbon in grassland, which is conditional on long-term management practices and climate (Ciais *et al.*, 2005); for example, the loss of soil carbon stocks in European grasslands have been observed in cases of severe drought. The sequestration process is also likely to face saturation levels that will limit the sequestration rates over the long term. Thus, there is a strong case for research and development policies to further assess mitigation potentials and develop appropriate institutional frameworks for underpinning the application of carbon sequestration practices in grasslands on a landscape scale over the long term.

Measurement methodologies

Further efforts are needed to develop and improve measurement methodologies. Compared with other mitigation strategies, soil carbon sequestration faces stronger challenges related to measurement. Direct measurement of soil carbon stocks requires soil sampling which, on a landscape scale, can be prohibitively expensive (FAO, 2011a). Methodologies for estimating changes in soil carbon stocks, based on the measurement of management activities, are being developed to improve the affordability of measuring carbon sequestration at a landscape scale (VCS, 2013), but further research is needed before policy-makers, farmers and carbon market participants alike can confidently invest in this mitigation strategy.

Non-permanence risks

Another challenge for implementing grassland soil carbon sequestration projects and policies is the risk of non-permanence; the risk that sequestered carbon is later released into the atmosphere if sustainable management practices cease. This can be caused by the conversion of grassland to arable lands or the resumption of unsustainable grazing practices. By contrast, reductions in supply chain GHG emissions are permanent and therefore do not face non-permanence risks.

The implications of carbon stock measurement challenges and non-permanence risks for the eligibility of carbon sequestration in existing policy frameworks, at international and national levels, are explored later in this chapter.

Institutional innovations on land tenure

Given that the viability of carbon sequestration practices depends on being able to establish them on a landscape scale, institutional innovations are needed for equitably aggregating individual household's carbon assets, in ways that allow both the community and individual households to derive benefits from soil (Tennigkeit and Wilkes, 2011). Land tenure can also present significant challenges for carbon sequestration practices in grasslands, particularly in the many rangeland areas that are communally managed without clear ownership or access entitlements. In these situations, there can be difficulties in establishing improved management practices, in the ownership of soil carbon assets, and in the ongoing monitoring of practices to manage non-permanence risks.

Extension, financial and regulatory incentives

Policies based on extension and financial and regulatory incentives will also play an important role in stimulating the adoption of grazing management practices. Again, the economic attractiveness of the various practices for enhancing soil carbon stocks will help to inform which combination of these policies is better placed to support these practices.

Sourcing of low emission intensity inputs

Input production is often an important source of emissions. This is particularly true for feed which contributes significantly to emissions, especially for monogastric production where it accounts for about 60 percent and 75 percent of all pig and chicken emissions, respectively. The main feed emissions are N_2O from fertilization (with manure or synthetic fertilizers) and CO_2 from land-use change. Energy is a further input associated with high emissions in monogastric systems and different energy sources also have different emission intensities. Therefore, producers could also mitigate by switching to less emission intensive energy sources.

The LCA framework is an extremely useful instrument for supporting the sourcing of low emission intensity inputs by producers, because it can trace supply chain emissions that are embodied in production inputs. The LCA framework can also be used to design sourcing strategies that have an overall mitigation effect and avoid unintended increases in emissions upstream and downstream of the livestock supply chains. For example, enteric emissions from ruminant animals can be lowered by increasing the proportion of high digestibility feeds in their feed rations. However, if the production of these feeds results in high emissions, then their inclusion in feed rations can cause total livestock supply chain emissions to increase (Vellinga and Hoving, 2011).

Policy requirements

Policies are needed to encourage producers to mitigate their emissions by switching to low emission intensity feeds, energy and other inputs. These policies include labelling and certification schemes to inform livestock farmers about the emission profiles of these inputs. The schemes will naturally be more effective when coupled with stronger policies to incentivize farmer purchases of low emission inputs and regulate the use of very high emission intensity feeds. Such policies could help to lower crop sector emissions, particularly where there is an absence of mitigation policies in the crop sector.

Adapting accounting rules

Emission accounting rules, such as those specified for the UNFCCC national GHG inventories, would present challenges for the input sourcing as a mitigation strategy (the UNFCCC framework is discussed in Chapter 7).

For example, emission reductions from cutting back on imported high emission feed would not be eligible for the importing country under these accounting rules; and national governments are unlikely to implement policies that do not contribute to their national mitigation targets. Similar obstacles would be present at the sectoral level within a country (Schulte *et al.*, 2012) because the same accounting rules assign upstream emissions to the sectors producing those inputs (e.g. reduced feed emissions are assigned to the crop sector).

In these cases, international and intersectoral policies and supply chain accounting rules that can assign emission reductions upstream of the farm to the livestock sector would be needed. Governments might be flexible about which national sectors are credited with emissions, as long as they can still count towards meeting their national mitigation goals. However, crediting domestic sectors with emission reductions located abroad will be more problematic.

The choice between regulating emissions at the livestock farm level or upstream in the energy or crop sector of origin will also have an effect on the coverage and cost-effectiveness of the policy. Naturally, a policy that targets all livestock and crop farm emissions will cover more emissions than one that excludes the non-feed part of crop sectors' emissions. However, it may be more pragmatic to apply the mitigation policy to livestock farms only because, by engaging a smaller number of producers, administrative costs for government and firms might be lower.

Need for information on emission intensity of inputs

It is likely that efforts to reduce the life cycle emissions of animal products will be driven by supermarkets and consumers more than by governments, for the reasons explained above. As discussed, labelling and certification programmes can help to incentivize mitigation by informing consumers (including livestock producers as consumers of input products such as feed and energy) about the emission attributes of products at different stages along livestock supply chains. The success of these programmes will largely depend on having broadly accepted metrics and methods to compute emissions and reasonably accurate information about the emission intensities of inputs and products. An emission quantification framework, such as the one developed by the LEAP,[39] could fill this need by guiding low-emission, input-purchasing decisions by livestock producers.

Technological breakthroughs

Although the adoption of advanced mitigation technologies and practices that are still under development were not assessed in Chapters 5 and 6, it is very likely that high additional mitigation potential can be achieved through new technological developments.

Research and development

Pursuing a research and development strategy could accelerate the availability of promising options. There is a range of mitigation options that have high potential, but require further testing and development before they can be considered viable. A prime example is the use of anti-methanogen vaccines which is very promising due to their wide applicability across all ruminant systems, including in some grazing systems where there is minimal contact between animals and livestock farmers (FAO 2013c). According to some studies (USEPA, 2006 and Whittle *et al.*, 2013), if this technology was further developed and made commercially available it would have the potential to be a relatively low-cost mitigation option. Other promising options, which also require additional research and development, include the genetic selection of cattle with low (enteric CH_4) emissions, and the use of nitrates as mitigating agents in animal diets (FAO, 2013c).

Financial and regulatory incentives

Further, while research and development initiatives are essential for the provision of new and improved mitigation options for the sector, financial and regulatory incentives can also drive mitigation technology development by the private sector. By making emissions costly or mitigation profitable, these policies will motivate the livestock industry to search for and develop less emission-intensive practices and technologies.

Supportive policies for adoption of new technologies and practices

Naturally, the same policy approaches that were outlined to support the transfer and use of existing mitigation options will also be needed to support the adoption of new practices/technologies once they become available.

7.4 EXISTING POLICY FRAMEWORKS FOR MITIGATION THROUGH LIVESTOCK

While research into practices and technologies for the mitigation of agricultural emissions has matured into a large body of valuable work, there has been much less progress in developing effective mitigation policies. At the global level, mitigation policies for all sectors, including agriculture, is primarily driven by the Kyoto Protocol to the UNFCCC. There are also regional, national and subnational policies and programmes for livestock

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[39] www.fao.org/partnerships/leap

that are both linked to and independent from the Protocol. However, the mitigation incentives that are currently provided by this collection of policies and programmes are quite weak.

This section presents a summary of existing mitigation policy frameworks that are relevant to the livestock sector.

The Kyoto Protocol

The Kyoto Protocol to the UNFCCC establishes legally-binding mitigation targets for developed country signatories. However, there are some major limitations to the effectiveness of the Protocol. The first is that not all of the Protocol's Annex I[40] countries (affluent countries) are party to the Protocol. The largest of these is the United States of America which has never ratified the Protocol. Canada withdrew in 2011, while Japan, New Zealand and the Russian Federation have not committed to targets in the Protocol's second commitment period (2013-2020). Second, the Protocol does not impose legally binding targets on non-Annex I countries (low income countries). As a consequence of these limitations, the 37 Annex I countries that have binding targets in the Protocol's second commitment period (2013-2020), accounted for a paltry 13.4 percent share of global anthropogenic GHG emissions in 2010 (UNEP, 2012). With regard to livestock, these countries accounted for a similarly low 16 percent share of direct[41] global emissions from livestock in 2005.[42]

Another limitation is that only two Annex I countries, namely Denmark and Portugal, have elected to report carbon stock changes associated with grazing land management under Article 3.4 of the Kyoto Protocol. All the other countries preclude it from their national GHG inventories and national mitigation targets. The challenges with measuring carbon stock changes and non-permanence risks contribute to countries' reluctance to nominate this as an eligible mitigation source.

The role of carbon markets

Carbon markets, in which carbon emission permits and reductions can be traded, have been put in place by a number of countries and jurisdictions to curb GHG emissions. Putting aside the lack of concerted political commitment to reduce emissions, which affects the penetration of all mitigation policies alike, Newell *et al.* (2011) report that carbon markets have, in general, functioned reasonably well, and are slowly growing rather than shrinking.

Despite this progress, carbon markets currently provide very limited mitigation incentives for the sector. They either do not include livestock sector emissions or provide only a limited coverage. This is partly due to difficulties in accurately and cost-effectively measuring emission reductions. However, with continued research and development to improve measurement methodologies and the ongoing evolution of market-based instruments, the role of carbon markets should increase over the long term.

Kyoto Protocol-compliant carbon market mechanisms

Countries with binding targets under the Kyoto Protocol can determine the suite of policies they use to meet these targets. To date, very few carbon market mechanisms have been established at the national or international levels. These include the EU Emission Trading Scheme, the Australian Carbon Pricing Mechanism and the New Zealand Emission Trading Scheme.

The volume and value of emissions traded on the Kyoto-compliant markets as a whole grew by 114 percent and 31 percent, respectively, between

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[40] The United Nation Framework Convention on Climate Change divides countries into three main groups according to differing commitments: Annex I Parties include the industrialized countries that were members of the OECD in 1992, plus countries with economies in transition. Non-Annex I Parties are mostly developing countries. Certain groups of developing countries are recognized by the Convention as being especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those prone to desertification and drought. Annex II Parties consist of the OECD members of Annex I, but not the economies in transition Parties.

[41] Enteric CH_4 and manure-related N_2O and CH_4 emissions.

[42] Estimated using the GLEAM model, but based on UNFCCC inventory accounting rules for livestock.

2008 and 2011. (Peters-Stanley and Hamilton, 2012; Hamilton *et al.*, 2010). The volume and value of emission allowances traded in the EU Emission Trading Scheme, the world's largest and most liquid carbon market, grew by 153 percent and 47 percent, respectively, over the same period. However, the combined effects of the current global recession and lower than projected emissions have caused an oversupply in EU emission allowances, and prices have been falling since 2008 (Newell *et al.*, 2012).

Furthermore, these market-based mechanisms have not played a role in the mitigation of livestock emissions because none of them includes agriculture, except for the Carbon Pricing Mechanism in Australia which is linked to a carbon offset scheme known as the Carbon Farming Initiative.

Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM), established under the Kyoto Protocol, is an offset scheme that allows developed countries to meet their national mitigation obligations by funding mitigation projects in developing countries. While all the main mitigation sources from the livestock sector can be included in the CDM projects, this instrument offers limited opportunities for livestock emissions mitigation.

The trade of certified emission reductions derived from carbon sequestration on agricultural lands is not permitted in compliance markets such as the EU Emission Trading Scheme; and these regulations effectively prevent demand for soil carbon sequestration projects in the CDM (Larson *et al.,* 2011). While projects that reduce enteric and manure emissions do not face this obstacle, the only livestock projects that have been registered are manure management projects related to biogas use and reduction. This reflects the fact that there are fewer implementation and measurement issues for practices that reduce CH_4 emissions from stored manure than there are for other livestock mitigation practices. There are currently 193 manure management projects registered under the CDM, with an estimated annual mitigation potential of 4.4 million tonnes CO_2-eq.[43]

High transaction costs due to the design of the CDM, measurement challenges and the frequent need to coordinate actions of multiple land users are reported as an obstacle to the establishment of agricultural land use projects in the CDM (Larson *et al.,* 2011). These factors raise the costs of participation in the CDM, particularly for smallholders.

While Larson *et al.* (2011) have reported that the CDM as a whole was on track to exceed its initial expectations, an oversupply of CDM credits combined with concerns about their credibility and restrictions on the use of CDM credits in the EU Emission Trading Scheme caused a large fall in credit prices at the end of 2012, casting some doubt over its future (Newell *et al.*, 2012; Marcu, 2012, Wilkes *et al.*, 2012).

Voluntary carbon markets

Contrary to Kyoto-compliant markets, voluntary carbon markets offer widespread eligibility of livestock sector mitigation options, including soil carbon sequestration. However, with a low supply of credits, transactions related to the sector have so far been very limited.

The voluntary carbon market is small compared with the Kyoto-compliant market.[44] In 2011, a volume of 95 million tonnes CO_2-eq was transacted in the world's voluntary carbon markets, compared with 131 million tonnes CO_2-eq and 94 million tonnes CO_2-eq, in 2010 and 2009, respectively (Peters-Stanley and Hamilton, 2012; Peters-Stanley *et al.*, 2011; Hamilton *et al.*, 2010). In 2009, close to half of all transactions took place on the

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[43] This figure was estimated by summing the emission reductions, stated by project participants, from each individual project accessed through the CDM online registry. See http://cdm.unfccc.int/Projects/projsearch.html.

[44] In 2011, the value of transactions on the voluntary carbon market was worth US$576 million, compared with US$3.3 billion in the primary CDM market, and US$147.8 billion for the European Union's Emission Trading Scheme (ETS). In terms of CO_2eq quantities, the voluntary market transacted 95 million tonnes CO_2-eq compared with 291 million tonnes CO_2-eq in the primary CDM market and 7 853 CO_2-eq in the European Union's ETS (Peters-Stanley & Hamilton, 2012).

Chicago Climate Exchange (CCX)[45] (Hamilton *et al.*, 2010). However, with the closure of the CCX in 2010, over-the-counter (OTC)[46] transactions picked up the slack and their share of transactions dramatically increased to 97 percent.

Credits from agricultural soil projects have typically comprised a small share of total OTC transactions, ranging from 0 to 3 percent between 2009 and 2011. OTC transactions of livestock CH_4 credits have also accounted for relatively small shares, ranging between 2 percent and 4 percent over the same period. On the other hand, credits linked to reduced deforestation accounted for larger shares of between 7 percent and 29 percent in this period (Peters-Stanley and Hamilton, 2012; Peters-Stanley *et al.*, 2011; Hamilton *et al.*, 2010).

A major constraint to the supply of soil carbon credits in voluntary markets is the lack of robust accounting methodology for CO_2 removals from grassland activities. Two methodologies have been validated for this purpose under the Verified Carbon Standard (VCS), which is the most commonly applied standard, covering 43 percent of all voluntary carbon market credits in 2011 (Peters-Stanley and Hamilton, 2012); although it is not clear that either of these are suitable for the cost-effective measurement of sequestered carbon on the landscape scale. FAO is developing a VCS methodology which, at the time of writing, is undergoing its second and final independent validation. Once validated, this methodology, which relies heavily on the use of biogeochemical modelling to lower soil sampling requirements, will provide a cost-effective solution to the measurement of soil carbon stock changes in grasslands on a large scale.

In addition to the limitations and uncertainties raised about carbon markets in the above section on compliance markets, carbon sequestration projects on agricultural lands face greater obstacles than other types of agricultural mitigation projects when engaging with market mechanisms. Concerns about the permanency of carbon sequestration and the credibility of related credits increase the complexity of accounting rules and reduce demand for these credits (Larson *et al.*, 2011). This issue, combined with the greater challenges of measurement and coordination, particularly where land is communal or where there are open access tenure arrangements, can make soil sequestration projects less attractive to investors.

Nationally Appropriate Mitigation Actions (NAMAs)

Nationally Appropriate Mitigation Actions can provide further incentives for mitigation but, so far, the inclusion of the livestock sector has been fairly limited. NAMAs include voluntary policies and actions to be undertaken by non-Annex I Parties to the Kyoto Protocol to reduce GHG emissions, which may be funded domestically or by industrialized countries.

As part of the Copenhagen Accord, non-Annex countries were invited to communicate information on NAMAs at the 15th session of the Conference of the Parties to the UNFCCC (COP 15) in 2009. A number of countries responded and provided information to the UNFCCC Secretariat on their proposed targets and actions. Among the NAMAs submitted to date, only six countries have explicitly included livestock as part of their mitigation strategy (Brazil, Chad, Jordan, Madagascar, Mongolia and Swaziland). Of these, only Brazil has submitted a quantitative target (Box 5).

National GHG inventories

While not a policy instrument per se, accurate national GHG inventories established in accordance with the IPCC Inventory Guidelines (IPCC, 2006), provide critical support for national mitigation policies by establishing GHG emission baselines for sectors and for identifying possible emission reduction pathways (Smith *et al.*, 2007). The IPCC guidelines provide methods for estimating emissions by sources and removals by sinks for differ-

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[45] CCX operated as a cap and trade programme, with an offset component, between 2003 and 2010. It was relaunched as the Chicago Climate Exchange Offsets Registry Program in 2011, but trade levels have remained very low since 2010.

[46] OTC transactions refer to the decentralized private exchanges in which buyers and sellers interact directly through a broker or an online retail "storefront" (Peters-Stanley and Hamilton, 2012).

BOX 5. BRAZIL'S NAMA AND PROGRESS IN ITS LIVESTOCK SECTOR

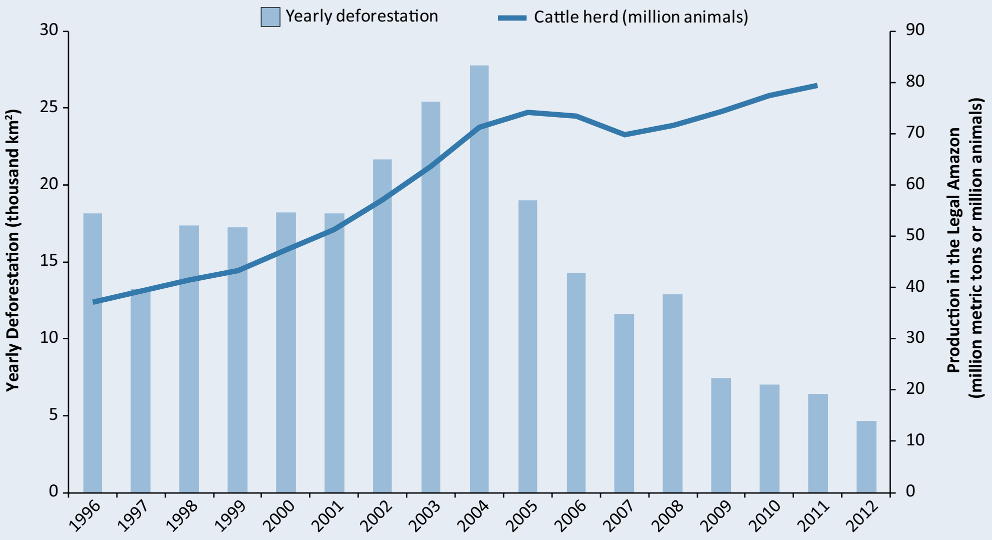
In its NAMA submission, Brazil has taken a global leading role in the mitigation of GHG emissions from the livestock sector, committing to a range of ambitious mitigation targets over the ten-year period from 2011 to 2020.[1] These include actions to directly reduce livestock sector GHG emissions and increase removals in grasslands: restoring grazing land (estimated reduction: 83–104 million tonnes CO_2-eq by 2020); and integrating crop-livestock farming (estimated reduction: 16–20 million tonnes CO_2-eq by 2020).

In its NAMA, Brazil also committed to a range of actions that will have an indirect but still substantial mitigation impact for its livestock sector, either by limiting deforestation that may be attributed to the sector, or by increasing mitigation in areas that are devoted to feed production for the sector. These actions include:

- reducing deforestation in the Amazon (estimated reduction: 554 million tonnes CO_2-eq by 2020);
- reducing deforestation in the Cerrado (estimated reduction: 104 million tonnes CO_2-eq by 2020);
- no-till crop planting (estimated reduction: 16–20 million tonnes CO_2-eq by 2020); and
- biological fixation of N (estimated reduction: 16–20 million tonnes CO_2-eq by 2020).

In support of these pledges, the Brazilian government established the ABC programme, which provides a credit line for special loans to finance various mitigation practices outlined above, as well as from animal waste treatment, which is estimated to generate a further 6.9 million tonnes CO_2-eq in emission reductions by 2020. The ABC programme has an estimated a budget of R$197 billion.[2]

While large future gains in mitigation in livestock are anticipated from the ABC programme, strong recent growth in cattle productivity has already allowed Brazil to increase the size of its cattle herd in the face of declining rates of deforestation in the Legal Amazon, since 2004.



Source: Bastos, 2013.

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[1] http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf

[2] http://www.agricultura.gov.br/desenvolvimento-sustentavel/plano-abc

ent sectors, including livestock, that vary according to their degree of complexity. Using the simplest Tier 1 methods, default emission factors can be applied to total numbers of animals, which vary by species and according to which broad region they are located in and, in the case of manure emissions, according to annual average temperatures. While Tier 1 methods are simple to use they are relatively inaccurate and shed no light on possible mitigation pathways. The IPCC guidelines also outline more sophisticated Tier 2 or 3 methods for estimating GHG emissions, which incorporate variations in animal size, function, feed management and other production factors which drive emissions. These methods allow more accurate estimation of emissions and, more importantly, the identification of pathways for emission reductions. Nevertheless, there is still significant scope to improve the utility of these methods for identifying mitigation opportunities in the livestock sector, especially in regard to measuring the link between feed quality and enteric emissions (FAO, 2013c). There is, therefore, a key role for further research and development to support more accurate national inventories by assisting countries that are currently using simple Tier 1 methods to switch to Tier 2 and Tier 3 methods, and to develop more accurate approaches with greater utility for identifying mitigation solutions.

Research and development, extension and climate funds to support mitigation

Funds in support of mitigation

In addition to carbon markets, there is a range of complementary sources of mitigation finance. These include multilateral funding sources such as the Green Climate Fund,[47] the World Bank, and the Global Environment Facility,[48] as well as domestic funding sources such as national development banks and nationally sponsored climate funds (e.g. the Spanish Carbon Fund),[49] which are making increasing contributions to mitigation finance (Venugopal, 2012). There may also be good opportunities for the public sector to design financial instruments to attract private sector co-investment into mitigation projects, perhaps by managing risks that the private sector is not willing to take on (Venugopal, 2012).

Research, development and extension initiatives

As mentioned, significant additional research and development is needed to build the evidence base for existing and new mitigation practices and technologies. There are some existing research projects and initiatives at international and country levels playing this role, which could be expanded. One of the main research initiatives at a global level is the Global Research Alliance (GRA) on agricultural GHGs, which focuses on the research and development of technologies and practices to increase food production without increasing emissions. It was launched in December 2009 and now has more than 30 member countries. The GRA builds on increasingly strong research programmes developed at national level, and thus has access to numerous scientists and engineers to create cross-cultural and multidisciplinary teams to deliver innovative and practical solutions. Research efforts are organized across different agricultural subsectors, and include a livestock research group that aims to find solutions to reduce the GHG intensity of livestock production systems and increase the quantity of soil carbon stored in grazing lands (GRA, 2013). There are several country-led initiatives that are supporting research, development and extension efforts in this area, some of which directly support the GRA. For example, the Canadian Agricultural Greenhouse Gases Program (AGGP), which focuses on knowledge creation and the transfer of

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[47] The Green Climate Fund is a mechanism for affluent countries to support adaptation and mitigation in developing countries that was established at COP 16. It aims to mobilise US$100 billion per year from both public and private sources by 2020. (http://unfccc.int/cooperation_and_support/financial_mechanism/green_climate_fund/items/5869.php).

[48] The GEF brings together 182 countries in partnership with multiple stakeholders to address global environmental issues, including climate change, offering grants for technical assistance and knowledge transfer (http://www.thegef.org/gef/whatisgef). It is the world's largest and oldest multidonor financing mechanism for mitigation.

[49] https://wbcarbonfinance.org/Router.cfm?Page=SCF

Credit: ©FAO/Ishara Kodikara

technologies for mitigation.[50] A similar but larger initiative is the Australian Carbon Farming Futures program, which will provide US$397 million to fund a range of research, demonstration and extension activities to help farmers benefit from the country's Carbon Farming Initiative (CFI): filling research gaps into new technologies and practices for mitigation; research in real farming situations; extension and outreach activities; and tax offset for farmers purchasing conservation tillage equipment.[51] Another knowledge-based initiative is the Scottish Climate X Change,[52] which is a centre of expertise based on the collaboration of the country's leading research and higher education institutes. The centre uses this academic network to generate evidence and provide advice to all sectors including agriculture farmers about climate mitigation and adaptation practices. The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) is a further notable initiative for generating knowledge, practices and technologies for GHG mitigation in agriculture.[53]

In addition to the GRA there are other important international initiatives that are investing in research, develop and extension activities. For example, the AnimalChange project is a research project involving 25 public and private partners from European and non-European countries, which seeks to develop and provide evidence for mitigation and adaptation strategies appropriate at farm, country and regional scales in the European Union, Latin America and Africa. The project has a €12.8 million budget over four years, and is mostly funded by the European Commission.[54] Another important international initiative is the Global Methane Initiative (GMI), a multilateral partnership established to foster international cooperation for reducing CH_4 emissions and advancing the recovery and use of CH_4 as a clean energy source. More than 40 countries collaborate in the initiative in coordination with the private and public sectors, researchers, development banks and non-governmental organizations. The GMI targets five major CH_4 sources, including agriculture where it focuses on anaerobic digestion systems for manure management. It focuses on developing strategies and markets for the abatement and use of CH_4, and engages in capacity building, information exchange and site-specific resource assessments to promote the adoption of mitigation technologies.

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[50] http://www4.agr.gc.ca/AAFC-AAC/display-afficherdo?id=1331047113009&lang=eng

[51] http://www.daff.gov.au/climatechange/carbonfarmingfutures

[52] http://www.climatexchange.org.uk

[53] http://www.agresearch.co.nz/our-science/land-environment/greenhouse-gas/Pages/default.aspx

[54] http://www.animalchange.eu

Reducing Emissions from Deforestation and Forest Degradation (REDD+)

Since its 16th meeting, the Conference of the Parties of the UNFCCC has adopted the Reducing Emissions from Deforestation and Forest Degradation (REDD+)[55] programme in developing countries as an important mitigation strategy in the forestry sector. Global and national REDD+ mitigation efforts are supported by multilateral initiatives such as the UN-REDD programme, Forest Carbon Partnership Facility (FCPF) and Forest Investment Program (FIP), hosted by the World Bank.[56] These initiatives rely on the provision of financial incentives and technical support for developing country adoption of REDD+ practices. Up to US$30 billion per year in financial flows are expected to become available for REDD+[57] because the conversion of forest to grazing land for livestock production is one of the drivers of deforestation, the REDD+ strategy has an important role in abating emissions from the livestock sector. The role of agriculture as a driver of deforestation has gained recognition in UNFCCC REDD+ negotiations since 2012 (Wilkes *et al*., 2012).

Private sector initiatives

The livestock industry is playing an increasing role in the development of mitigation strategies. The last ten years have seen a rise in private sector initiatives involved in developing targeted responses to sustainability challenges.

Voluntary mitigation programmes

In some cases, the livestock sector has taken a leadership role in better identifying the environmental impacts of production and the potential mitigation options to reduce environmental impact. The International Dairy Federation's (IDF's) Common Carbon Footprint Approach for Dairy is one such example (IDF, 2010). Based on life-cycle assessment, the methodology developed is the result of an intensive process involving international experts and dairy companies to develop common guidelines to calculate the carbon footprint of the dairy sector. Such initiatives not only identify GHG emission hotspots and reduction opportunities, but can also enhance efficiency across the supply chain. In relation to this international effort, an increasing number of national dairy associations are engaging in voluntary mitigation programmes. The meat industry is also progressively engaging in this way, as illustrated by several national initiatives, for example by the US Cattleman Association and a number of key pork producing countries (IMS, 2012). Additional efforts also include the tools recently released by the US National Pork Board and Teagasc-Bord Bia Partnership to assess and better understand the industry's carbon footprint.[58]

Sustainability platforms

Sustainability platforms, bringing together a number of sectors to work collectively on developing and adopting more sustainable practices, are also active. For example, the Sustainable Agriculture Initiative (SAI), originally set up in 2002, now draws on an international membership of over 50 members, including some of the world's biggest agricultural production companies.[59] Sustainability programmes have progressed across a number of product areas, including beef and dairy and with a focus on climate and water.

Growing involvement of retailers

Retailers have also taken important strides in driving improved environmental performance. Walmart's Global Sustainable Agriculture Goals is one such retailer programme that is investing substantially in more efficient and sustainable livestock supply chains. The recent announcement in April 2013 of the partnership between The Nature Conservancy (TNC), a leading conservation or-

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[55] The 'plus' refers to conservation actions, sustainable forest management, and the enhancement of forest carbon stocks, in addition to actions for preventing deforestation and forest degradation.

[56] http://www.un-redd.org/AboutREDD/tabid/102614/Default.aspx

[57] www.un-redd.org

[58] http://www.pork.org/Resources/1220/CarbonFootprintCalculatorHomepage.aspx and The 'Beef Carbon Navigator' http://www.teagasc.ie/news/2012/201209-25.asp

[59] www.saiplatform.org

ganization, Marfrig Group, one of the world's largest food producers, and Walmart Brazil to invest in a targeted sustainability programme with beef operations in southeastern Pará, Brazil, demonstrates the more active role retailers are taking in the livestock sector towards driving sustainable practice.

Need for further interaction across supply chains actors

These developments are mostly motivated by changing consumer preferences and the increasing awareness of stakeholders along the livestock supply chain. The challenge for the private sector will be to ensure that policies and initiatives are implemented by producers and sustained over the long term, through a process of continuous improvement. In addition, the connection between producers and consumers needs attention to ensure that the livestock sector is meeting consumer needs in an appropriate and relevant manner. This drives an ongoing need to better understand the life cycle of livestock products and encourage further interaction between decision-makers across the supply chain.

7.5 CONCLUSIONS

Strategies for concomitant development and mitigation objectives

To have traction among policy-makers, livestock mitigation policies need to be consistent with the overall development goals of the country, and they must be part of a vision of how the sector should and could develop. A key requirement for developing country participation, where most of the mitigation potential in the livestock sector is found, is the creation of strategies that can serve both development and mitigation objectives.

It is estimated that up to one-third of the livestock sector's emissions could be reduced in the short to medium term by the greater use of more efficient, readily available practices and technologies that can serve both of these objectives. While much of the livestock sector's mitigation potential could be achieved profitably or at minimal cost (USEPA, 2006; Moran *et al.*, 2010; Schulte *et al.*, 2012), further assessments are needed to improve our understanding of how and where among the range of available mitigation practices, regions and production systems, development and mitigation goals can converge.

Investments and policies for enabling environments

Additional investments and partnerships are, however, required to encourage technological innovation and build institutional capacity to support and make use of these innovations. Extension and other knowledge exchange along with network activities are the principal policy instruments for closing the efficiency gap between more efficient farmers and their peers. At the same time, stronger policy frameworks are needed to better align private and public economic objectives, and to facilitate further uptake of all mitigation strategies. However, without strong internationally binding emission targets that are inclusive of agriculture and the world's most important emitting countries, the introduction of effective mitigation policies will remain a political and economic challenge. Trade-offs between mitigation and other environmental and socio-economic objectives must also be considered and managed. While efficiency-based GHG mitigation strategies can also improve efficiency in the use of other natural resources, policy safeguards are still needed to avoid unintended environmental, disease and socio-economic risks. For instance, a single-minded commodity-based focus on production efficiency can come at the expense of some ancillary services of livestock that are important for poor rural households, including their role as a store of wealth.

Additional research and development

There is a role for additional research and development in all mitigation strategies to improve existing technologies, develop new ones, but also to develop interventions that are based on packages of mitigation technologies suited for specific production conditions. There is also a need for more accurate and affordable methods for measuring emissions, to guide practice change and support more accurate national inventories. These challenges vary among livestock emission sources, by sector and region. For example, validated methodologies exist for measuring the recovery and use of CH_4 from stored manure as a clean energy source. The predominance of livestock biogas projects in the CDM offset scheme provides evidence of this.

Conversely, carbon sequestration in grasslands has tremendous potential, but more research and development is required to develop measurement methodologies. Furthermore, pilot studies and supporting institutional mechanisms are needed before the strategy can be incentivized on a meaningful scale. This will also improve the prospects for the greater inclusion of this strategy in national mitigation targets. Further, given the paucity of cost-benefit analyses for mitigation options, research and development to redress this neglect is vital. As discussed, knowledge about the economic attractiveness of these options is fundamental for the design of cost-effective mitigation policies.

Investing in mitigation in the context of weak incentive policies

On the whole, the mitigation incentives for livestock provided by existing international and national mitigation policies and programmes are very limited. Much of this weakness stems from the small proportion of countries and emissions that are covered by the Kyoto Protocol, and its related market-based instruments. Further incentives are provided by NAMAs; however, these pledges only involve voluntary mitigation ambitions which, with the notable exception of Brazil, so far exclude specific mitigation targets for livestock. In the absence of a stronger and more inclusive international agreement to reduce emissions, action will largely depend on identifying profitable opportunities for investing in mitigation. These will be driven by reduced production costs or market premiums for low emission intensity products. The design of financial instruments that allow the public sector to underwrite the risks of mitigation projects, which the private sector is unwilling to take on board, could play an important catalytic role in attracting private sector co-investment into these projects.

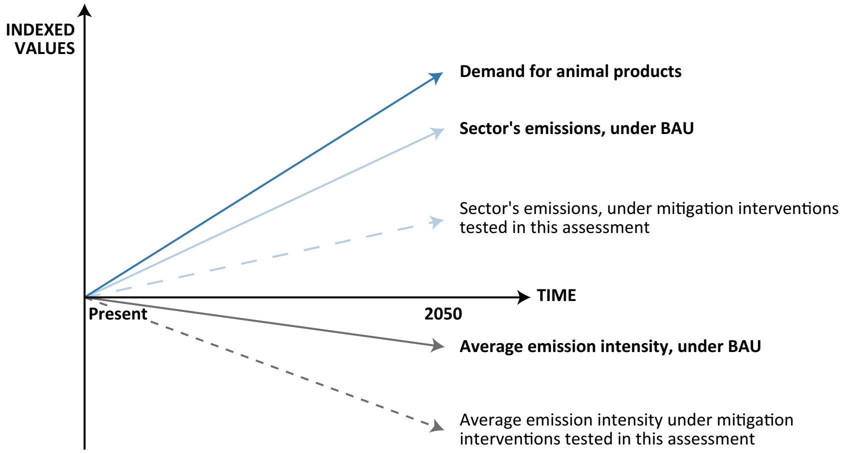
Emission intensities versus absolute emissions

The future overall emissions of the sector will depend on the combined effect of emission intensity reductions and growth in production, which is projected to increase by about 70 percent between 2010 and 2050 (FAO, 2011c).

Under the BAU outlook, the global average emission intensity of livestock supply chains is expected to decrease slightly, as more efficient practices are adopted and as most of the sector's growth takes place in commodities with relatively low emission intensities. This assessment has shown that narrowing the emission intensity gap within production systems could reduce of emission intensities by about one-third of current levels. On a global scale, it is unlikely that the emission intensity gains, based on the deployment of current technology, will entirely offset the inflation of emissions related to the sector's growth (Figure 28). However, the full technical mitigation potential of the sector, i.e. the effect of applying all available mitigation techniques, irrespective of their cost, is greater than a third of current emissions and it is possible that technological breakthroughs will allow mitigation above and beyond current estimates. Furthermore, in regions where expected production growth is low, reductions in emission intensity may be able to fully offset sector trends.

These considerations, which were not included in the scope of this assessment, require further research. This would involve economic and social analyses to better understand regional specificities, differences between systems and interactions between rural development, food security and mitigation. It would also require to assess the effect that efficiency gains way have on consumers' price and consumption levels. This research is required to better understand the overall mitigation potential in the sector and to identify livestock's role in global and multisector efforts for addressing climate change.

FIGURE 28. Interactions between trends in livestock production, GHG emissions and mitigation efforts.



The need for international, multisector, multistakeholder action

Due to the size and complexity of the livestock sector, the design and implementation of cost-effective and equitable mitigation strategies and polices can only be achieved through concerted action by all stakeholder groups (including producers, industry associations, academia, the public sector and intergovernmental organizations). Moreover, given the nature of climate change as a global public good and the sector's socio-economic challenges, collective global action is both welcome and needed. And because of the increasing global economic integration of livestock sector supply chains, unilateral actions to mitigate GHG emissions will be much less effective than more internationally coordinated actions. For example, where strong mitigation policies are limited to one country, there are risks that a large share of that country's emission reductions will be offset or "leaked" into unregulated sectors abroad (Golub *et al.*, 2012). In addition, unilateral policies invariably raise issues about competitiveness and fairness for sectors that are exposed to international trade.

While the main official mechanism for international and multisectoral action on GHG mitigation is provided by the UNFCCC, important mitigation efforts are also being carried out on local industry scales, often led by the private sector. There is, however, a need for more support from global initiatives that are focused on livestock-specific issues, and that can effectively integrate and mainstream the mitigation and development objectives pursued by sector stakeholders.

An example is LEAP, which gathers partners from the private sector, governments, civil society organizations, research and international organizations that have agreed to develop common metrics to define and measure environmental performance of livestock supply chains.[60] The Global Agenda of Action in support of Sustainable Livestock Sector Development is a closely related initiative by a similar group of stakeholders from all parts of the livestock sector, which tackles the issue at the level of implementation, by focusing on practice change and continuous improvement.[61] It draws on the differing strengths of each stakeholder group to build the trust and cohesion that are essential for concerted international action along the sector's entire supply chain.

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[60] www.fao.org/partnerships/leap

[61] www.livestockdialogue.org

APPENDIX

SUPPLEMENTARY INFORMATION ON METHODS

TABLE A1. Overview of the approach used for the computation of feed emissions in GLEAM

Species/system	Step 1 Categories of feed and feed materials included in feed basket	Step 2 Proportions of feed categories and materials in feed basket	Step 3 Amount of feed consumed by animals	Step 4 GHG emissions associated with feed production
Chicken backyard	Categories and relative materials in feed basket are: • feed crops, e.g. first grade crop products fed to animals, such as cassava and soybean • second grade crops, e.g. crop products not edible by humans and fed to animals, such as grains, pulses and bananas • crop residues, e.g. straw, maize stover • by-products, e.g. soybean cakes and brans • forage, e.g. material collected by free ranging, such as grass and legumes • swill	• All material locally-sourced • Proportion of each category in the feed basket based on literature and expert knowledge • Within categories, proportions of feed materials are defined as follows: - feed crops, second grade crops, crop residues and by products: estimated for each GIS cell, based on the relative proportion of materials in the country and agro-ecological zone where the cell is located - swill and material from free ranging: composition not specified	Based on energy requirements	Computed by material: • feed crops, second grade crops, crop residues and by products: estimate based on cropping parameters averaged over country and agro-ecological zone, allocation factors applied to all except feed crops • swill and material from free ranging: none
Chicken intensive broilers and laying hens	Categories and relative materials in feed basket are: • feed crops: first grade crop products fed to animals, e.g. cassava, soybean and grains • by-products, e.g. oilseed cakes and brans • non-crop feed, e.g. lime fishmeal and synthetic amino acids	• No material locally-sourced • Proportion of each category and material in the feed basket are based on literature and expert knowledge	Based on energy requirements; N consumption was checked to be aligned with requirements	Computed by material: • feed crops and by-products: estimate based on cropping parameters averaged over FAO regions (for imported materials, such as soybean, emissions computed as national average in country of origin) • lime, fish meal and synthetic amino acids: standard emission factors from literature and databases, e.g. ecoinvent • transport of feed, based on estimates of local and international transport
Pig backyard	As for backyard chicken.			

(cont.)

TABLE A1. *(cont.)*

Species/system	Step 1 Categories of feed and feed materials included in feed basket	Step 2 Proportions of feed categories and materials in feed basket	Step 3 Amount of feed consumed by animals	Step 4 GHG emissions associated with feed production
Pig intermediate	Categories and relative materials in feed basket are: • feed crops, e.g. first grade crop products fed to animals, such as cassava and soybean • second grade crops: crop products not edible by humans and fed to animals, e.g. grains, pulses and bananas • crop residues, e.g. straw and maize stover • by-products, e.g. soybean cakes • forage, e.g. material collected by free ranging, such as grass and legumes • swill • non-crop feed, e.g. fishmeal and synthetic amino acids	• Part of material locally-sourced (swill, forage, crop residues, second grade crops) and part exogenous to the production site (feed crops, by-products, non-crop feed) • Proportion of each category based on literature and expert knowledge • Proportion of feed materials within exogenous categories based on literature and expert knowledge • Proportion of feed materials within locally-sourced categories estimated for each GIS cell, based on the relative proportion of materials in the country and agro-ecological zone where the cell is located	Based on energy requirements; N consumption was checked to be aligned with requirements	Computed by material: • locally-sourced materials: emissions estimate based on cropping parameters averaged over country and agro-ecological zone - allocation factors applied to all except feed crops • exogenous materials: estimate based on cropping parameters averaged over FAO regions (for imported materials, such as soybean, emissions computed as national average in country of origin) • swill and material from free ranging: none
Pig industrial	As for intensive chicken. Same categories and material except for lime.			
Cattle and Small ruminants	Categories and relative materials in feed basket are: • roughage: fresh grass, hay, legumes and silage, crop residues, sugarcane tops and leaves • by-products: bran and oilseed meals • concentrate: grains, molasses, pulp, oilseed	• Categories and their relative proportions in the feed basket based on literature and expert knowledge; these vary by country, herd (dairy and beef) and also by animal category (females, males and fattening meat stock) • For developed countries, feed materials and their relative proportions established on the basis of literature and expert knowledge • For developing countries, feed materials and their relative proportions established on the basis of relative availability in GIS cell	Based on energy requirements	Computed by category: • roughage: estimate based on cropping parameters of the GIS cell • concentrate: estimate based on cropping parameters averaged over FAO regions (for imported materials, such as soybean, emissions computed as national average in country of origin) • transport of feed, based on estimates of local and international transport

GLEAM COMPARED WITH THE *LIVESTOCK'S LONG SHADOW* ASSESSMENT

Both, the 2006 assessment and this more recent assessment rely on an attritional LCA and post-farmgate use similar system boundaries, from cradle to farmgate. However, within this broad common framework, this assessment relies on an entirely new computation framework: GLEAM. The main differences are presented in Table A6 and summarized below:

- This analysis relies on the GIS-based GLEAM developed at FAO for the computation of emissions by species, commodities, farming systems and climatic zones, whereas the 2006 assessment is mostly based on statistical tables.
- This update is computed for a three-year average around 2005, whereas the 2006 assessment is based on the period 2001 to 2004.
- Both assessments essentially rely on IPCC guidelines for GHG emissions but the *Livestock's long shadow* assessment uses the 2001 version, whereas this assessment uses the 2006 version. Furthermore, the two assessments use different warming potentials to compute emissions in CO_2-eq units: 296 and 298, and 23 and 25, respectively for N_2O and CH_4 in the 2006 assessment and this present report.
- In line with IPCC (2006), this assessment assumes stable soil organic carbon stocks under constant land use, i.e. when land has stayed within the same broad land use class over the past 20 years (pasture, crop, forest). On the other hand, *Livestock's long shadow* estimates emissions from losses of organic matter in cultivated soils and from livestock-induced desertification of pasture; this accounts for 0.12 gigatonnes CO_2-eq.
- This assessment includes CH_4 emissions from the production of rice products used as feed that could not be estimated at the time of preparing the *Livestock's long shadow* report because the information available was too limited; the emissions amount to 26 million tonnes CO_2-eq.
- The *Livestock's long shadow* assessment includes GHG emissions related to the production of feed (including pasture) fed to all animal species (for a total of 2.7 gigatonnes CO_2-eq), whereas this report only accounts for feed materials fed to the studied species, i.e. poultry, cattle, pig, small ruminants and buffalo (for a total of 3.2 gigatonnes CO_2-eq including rice products).
- All manure emissions were accounted for in the *Livestock's long shadow* assessment (for a total of approx. 2.2 gigatonnes CO_2-eq), but only emissions related to manure management and manure application on feed crops or pasture are accounted for in this report (for a total of 0.7 gigatonnes CO_2-eq and 1.1 gigatonnes CO_2-eq, respectively).
- Both assessments include emissions related to land-use change from deforestation for pasture and feed crops and limit the scope of the analysis to the Latin American region. Emissions related in *Livestock's long shadow* assessment were estimated to be 2.4 gigatonnes CO_2-eq compared to 0.65 gigatonnes CO_2-eq in this report. The significant difference is explained by: (i) different reference periods (1990–2006 and 2000–2010 for this assessment and *Livestock's long shadow*, respectively) and land-use change data sources (FAOSTAT and Wassenaar *et al.* (2007) for this assessment and Livestock's long shadow, respectively); (ii) the limitation of feed crop expansion to soybean expansion in Brazil and Argentina only in this assessment, compared to the inclusion of all feed crop expansion in Brazil and Bolivia in *Livestock's long shadow*; and (iii) different versions of the IPCC guidelines – see above.
- Whereas this assessment uses the IPCC methodology as a basis for the quantification of land-use change emissions, the approach in *Livestock's long shadow* is based a land-use change modelling framework that predicted potential land-use changes to 2010 based on projections from FAO (2003) and changes in forest cover.
- Emissions related to buildings and equipment were not included in the *Livestock's long shadow* report because of the limited available information. They were estimated in this assessment and amount to 24 million tonnes CO_2-eq.

TABLE A2. Methods and data sources used in this update and in the *Livestock's long shadow* assessment

Part of supply chain	Methods used in this update	Methods used in *Livestock's long shadow*
Upstream – feed production	• Feed baskets were established by species and production systems; part of the information required to establish the feed baskets was gathered from literature and expert knowledge; the remaining information was modelled in GIS • Feed consumption was computed for each species, based on requirements • Emissions per unit of feed computed in GIS environment based on local and regionally averaged parameters; emissions from land-use change computed at national level • Emissions related to national and international transportation computed on the basis of trade matrices and emission factors	• No feed basket established by species • Aggregated feed consumption statistics retrieved from FAOSTAT • Emissions related to feed production computed as the addition of: - global estimate of emissions associated with global fertilizers applied to feed crop (manufacturing and application) - global estimate of emission from on-farm fossil fuel use (for feed and animal rearing) - estimated emissions from forest conversion in the neotropics based on literature and IPCC 2001 guidelines - global estimate of emissions from cultivated soils through losses of organic matter, liming; emissions from rice not included - global estimate of emissions from livestock-induced desertification
Upstream – non-feed production	• Building and equipment used in animal production estimated by species, farming system and climatic zone, extrapolating information from literature and expert knowledge; embedded energy and related emissions then computed from existing databases	• Not included
Livestock production	• Enteric CH_4 emissions based on IPCC (2006) Tier 2 guidelines; feed basket estimated as explained above; animal production and herd structure modelled within the LCA model • Nitrous oxide and CH_4 emissions related to manure storage computed using IPCC (2006) Tier 2 guidelines and GIS technology; amount and composition of manure computed for each GIS cell and climatic data used to estimate emission factors; estimates made about the extent of principal manure management practices for different species, farming systems, regions and climatic zones • Levels of mechanization estimated by species, farming system and climatic zone, extrapolating information from literature and expert knowledge; energy efficiency, energy sources and related emissions then computed from existing databases	• Enteric CH_4 emissions based on IPCC (2006) Tier 2 guidelines; parameters required to compute emissions estimated for each species/region and production system from FAO databases and literature • Nitrous oxide and CH_4 emissions related to manure storage computed using IPCC (2006) Tier 2 guidelines; manure management practices estimated by species, farming system and region • On-farm energy use globally estimated based on literature data (feed and non-feed not distinguished – see above)
Post farmgate	• Levels of processing and transport distances estimated by commodity, farming system and region; related energy requirements gathered from literature and emissions then computed drawing on existing databases on emission intensity of the energy sector; transport emissions estimated on the basis of published case study data and FAOSTAT trade matrices	• Estimates of emissions from processing generated at global level based on published case studies and relative contribution of farming systems to overall output; published case study data and FAOSTAT trade matrices used to compute international transport

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As renewed international efforts are needed to curb greenhouse gas emissions, the livestock sector can contribute its part. An important emitter of greenhouse gas, it also has the potential to significantly reduce its emissions. This report provides a unique global assessment of the magnitude, the sources and pathways of emissions from different livestock production systems and supply chains. Relying on life cycle assessment, statistical analysis and scenario building, it also provides estimates of the sector's mitigation potential and identifies concrete options to reduce emissions. The report is a useful resource for stakeholders from livestock producers to policy-makers, researchers and civil society representatives, which also intends to inform the public debate on the role of livestock supply chains in climate change and possible solutions.

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