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.

* 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-

[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-

[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).

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 90^{th} 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 90^{th} 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).

[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).

[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,

[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

4 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

[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

[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]

[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.

[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.