Reducing greenhouse gas emissions from livestock:
Best practice and emerging options

GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES

SAI PLATFORM

Acknowledgements:

This publication is an initiative of the Livestock Research Group (LRG) of the Global Research Alliance on Agricultural Greenhouse Gases (GRA) and Sustainable Agriculture Initiative (SAI) Platform. It was proposed at a seminar in Dublin (2013) on greenhouse gas emissions in the livestock sector, with the aim to share information about mitigation options based on best practices. The study was commissioned by the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) in support of this initiative.

The co-chairs of the LRG and president of the SAI platform are very thankful for the contributions from a range of individual scientists in GRA member countries working together in the six networks within the LRG; and experts from the Beef and Dairy Working Groups of the SAI Platform. Their shared knowledge and expertise contributed to the relevance and robustness of this document. The participation of these scientists and experts and their institutions is gratefully acknowledged, and warm thanks are extended for their contribution to this document.

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AGRICULTURAL GREENHOUSE GAS
Research Centre

Foreword

*'**Reducing Greenhouse Gas Emissions from Livestock: Best Practice and Emerging Options**' is a joint effort of the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases and of the Dairy and Beef Working Groups of the Sustainable Agriculture Initiative (SAI) Platform.*

The Global Research Alliance on Agricultural Greenhouse Gases

The Global Research Alliance on Agricultural Greenhouse Gases (GRA) was founded in 2009 to bring countries together to find ways to grow more food without growing greenhouse gas emissions. The GRA facilitates voluntary actions between its 44 member countries to increase cooperation and investment in research and development activities to help reduce the emissions intensity of agricultural production systems, increase soil carbon sequestration, and improve the efficiency, productivity, resilience and adaptive capacity of farms and farmers, thereby contributing in a sustainable way to overall mitigation efforts, while still helping meet food security objectives. The GRA works across the agricultural sub-sectors of paddy rice, croplands and livestock.

The Livestock Research Group (LRG) of the GRA focuses on actions to reduce the emissions intensity of livestock while increasing food security. Through dedicated research networks, the LRG supports collaborative research and acts as a knowledge hub to share data and expertise with international organisations and industry bodies. This document summarises current best practices ready for implementation at the farm level as well as emerging options at various stages of research to reduce the greenhouse gas emissions intensity of livestock production across a range of farm systems. We hope this will be useful for the members of the SAI, as well as other industry partners and policy agencies, to provide information about existing opportunities to reduce emissions, and to collaborate in the development, trial and dissemination of additional mitigation options.

Harry Clark
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Martin Scholten
Co-chair, LRG
Wageningen UR

The Sustainable Agriculture Initiative Platform

On behalf of the SAI Platform – the global food and drink industry initiative for sustainable agriculture – I am tremendously pleased to welcome this excellent and updatable resource for the livestock sector highlighting options for reducing greenhouse gas emissions in its operations now and in the future.

How to increase food production while at the same time reducing its contribution to global climate change is one of the key questions that progressive food companies such as SAI members are seeking answers to.

Solutions can be found in science, but practitioners often do not find them sufficiently relevant, useful or actionable. Scientific research organisations wanting to develop effective solutions therefore need to ensure industry engagement as part of their work. We hope that the co-operation between the GRA and SAI Platform – which is exemplary of this type of research – inspires other collaborative efforts delivering science based solutions relevant to and useful for farmers.

In line with our belief that progress in sustainable agriculture can only be achieved through a partnering approach, we look forward to continued cooperation with the GRA to increase and improve joint impact.

Finally, I want to personally thank the GRA/LRG staff and their member scientists as well as SAI Platform's Beef and Dairy Working Group members. Now it is up to all of us to actively share this resource with practitioners among our membership, supplying farmers and other food businesses alike.

Dirk Jan de With
President, SAI Platform
Vice President, Procurement Ingredients & Sustainability, Unilever

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Part 2 — Intervention areas and detailed options

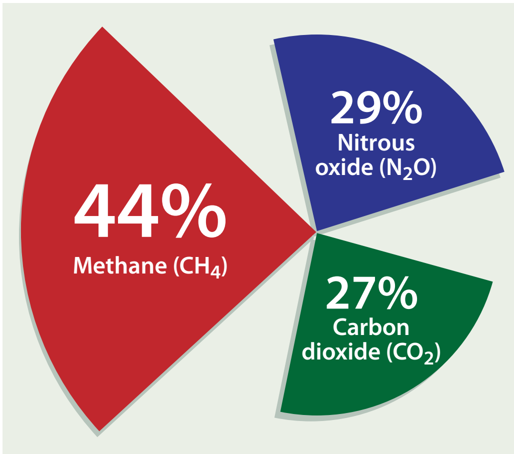
Part 3

Introduction

Livestock plays an important role in climate change. Livestock systems, including energy use and land-use change along the supply chain, accounted for an estimated 14.5% of total global greenhouse gas (GHG) emissions from human activities in 2010. More than half of these (about 65%) are related to cattle. Direct emissions from livestock and feed production constitute some 80% of total agriculture emissions, and thus need to be part of any effort to reduce the contribution of food production to global climate change.

Agriculture is estimated to contribute directly about 10-12% of total GHG emissions from human activities. Additional indirect emissions that can be attributed to agriculture arise from the clearing of forest land, fertiliser production and the use of fossil fuels in farm operations, storage and transport. Emissions directly associated with animal production have increased by about 1.1% per year since 2000, linked to a steady growth in demand for animal products. At the same time, the GHG emissions intensity of animal production (i.e. emissions generated on-farm for each kg of meat or per litre of milk produced) has decreased significantly (38% to 76% for various livestock products) from the 1960s to the 2000s. As demand for livestock is projected to continue to increase over the next decades, further reductions in emissions intensity are needed to limit the environmental burden from food production while ensuring sufficient supply of high quality, protein-rich food for a growing world population.

Emissions intensities currently vary widely within and across geographic regions and production systems, by a factor of two to more than four, especially for products from ruminant animals (meat and milk) but also for pork and poultry. Intensive animal production systems tend to have higher overall GHG emissions, but their emissions intensity is lower than in low-yield extensive systems. The gap between high and low emissions intensity producers in itself signals significant mitigation opportunities.

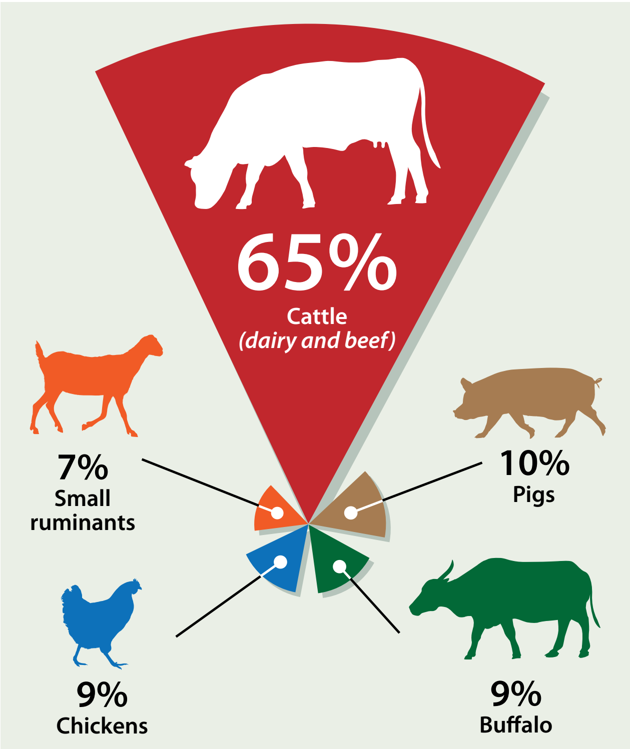


Livestock greenhouse gas emissions (Lifecycle Analysis, Gerber et al., 2013)

Reducing emissions intensity on-farm will not necessarily translate into lower absolute emissions, as these depend on total production and responses of farmers to wider market and policy signals. Nonetheless, since overall food demand is largely out of the control of individual farmers and even major individual businesses, a focus on emissions intensity on-farm presents a realistic approach to reduce supply-side emissions without precluding other actions to manage the demand for livestock products.

For all livestock production systems, opportunities exist and are being developed to decrease GHG emissions per unit of animal product further. Some of these options require novel technological interventions; others are 'simple' principles that can be applied already in most production systems.

Mitigation measures for animal production



Livestock greenhouse gas emissions per species (Lifecycle Analysis, Gerber et al., 2013)

This publication provides a practical overview of currently available best practices and promising developments for the near future to mitigate emissions, with a focus on on-farm GHG emissions from animal production. The diagram overleaf *(page 4)* summarises the different 'areas of intervention' and specific mitigation options that this publication covers, including the maturity of each option. Many options are specific to ruminant animals, but several are also applicable to non-ruminant (monogastric) animal production systems.

Interventions in the different parts of the sector are often linked and thus, when deciding on action, it is recommended to think about the effects of the intervention on net GHG emissions along the production chain as a whole (positive or negative). Possible side-effects of the intervention on economic performance and risk, other environmental or sustainability objectives (such as water quality, land and energy use), and the need to enhance food security in the context of a changing climate, will also need to be considered. To support such considerations, the main part of this document briefly flags other co-benefits for sustainability from individual mitigation options, as well as barriers and trade-offs in their implementation. Integrating best practices and tailor-made solutions offer the best opportunity for success.

Additional ways of mitigating GHG emissions from the livestock supply chain exist in the areas of energy use, transport, feed production and processing, food waste, and food consumption patterns. These options are not discussed in this publication but warrant concerted consideration by multiple decision-makers as part of a strategic approach to the role of agriculture in global climate change.

Guide to reading this document

The following chapters describe six broad areas where on-farm emissions from animal production can be reduced, broken down into twenty-two detailed intervention options. Many measures have already proven to be successful and are ready for implementation and wider use. Other measures are still at various stages of development, but are the subject of active research. These may offer opportunities for industry to help develop them further into viable solutions, and to ensure that supply chains are ready to adopt those measures once they are commercially available.

To support such varying modes of engagement, mitigation options within each area are grouped into different 'levels of maturity', indicating the readiness of the measure for implementation based on experiences in diverse settings. Those levels are:

Best practice – measure has been successfully implemented in diverse contexts, next step is scaling up

Pilot – pilot project has been carried out, next step is commercial development

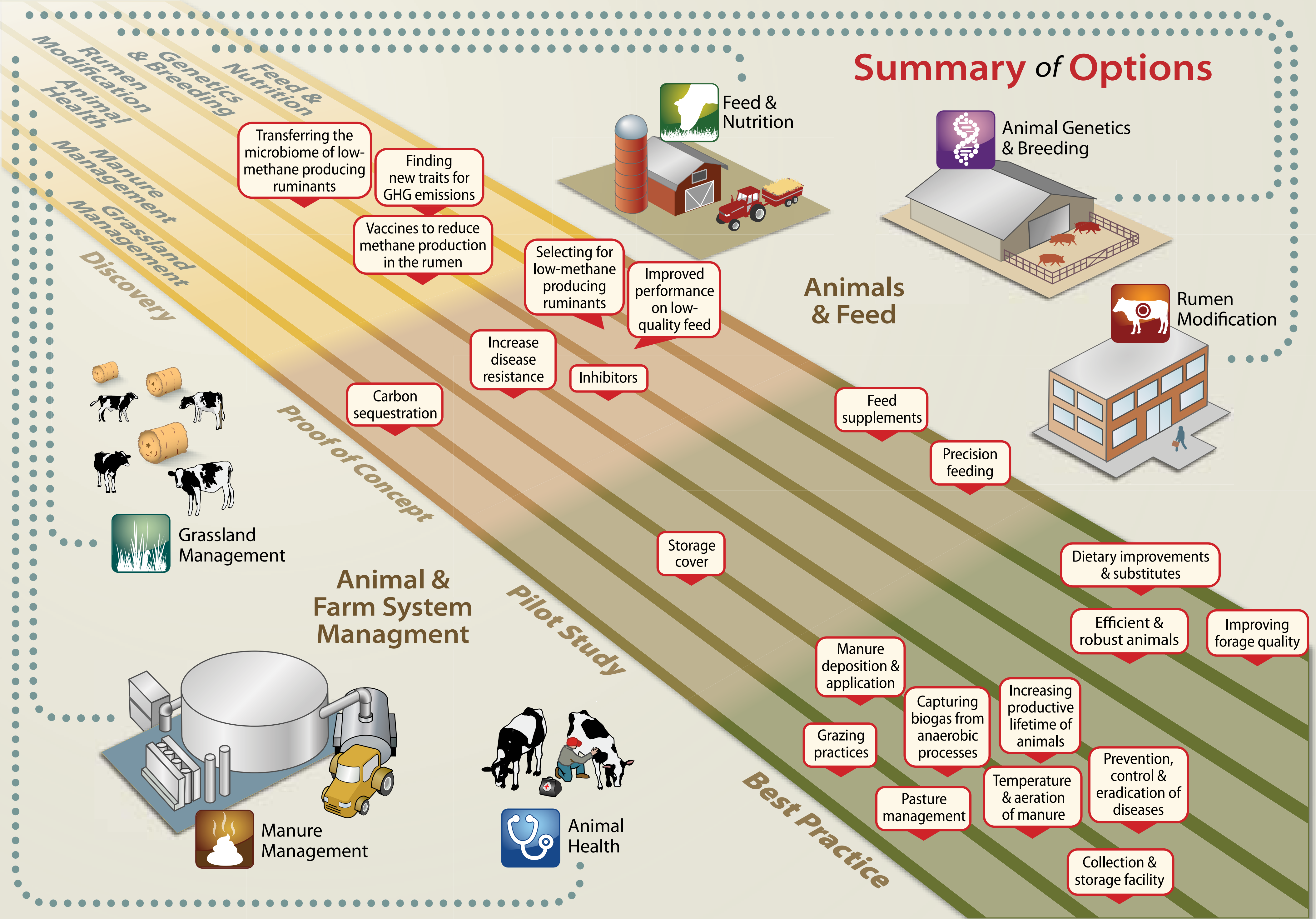
Proof of concept – the measure has been demonstrated in an experimental setting, next step is a pilot

Discovery – exploring promising concepts for future proof of concept

The potential magnitude of reductions in GHG emissions intensity from each individual option is indicated qualitatively, along with an estimate of their cost-effectiveness and implications for other sustainability goals (such as resource use, water quality, or resilience). Note that characterisations of mitigation potential are indicative only and rely on expert judgement across a range of studies and applications; the actual reduction potential, cost-effectiveness, practical feasibility, and wider social and environmental implications of mitigation options vary substantially among individual farms, farming systems and world regions. As a broad approximation, '**+**' indicates an emissions intensity reduction potential of typically 0-10%, '**++**' indicates 10-20%, and '**+++**' indicates more than 20%. Some options reduce emissions intensity but are often coupled with increased overall production, and hence will not necessarily result in a comparable change in absolute emissions. Note that for some specific options, the potential to reduce emissions is large for the specific source (and hence indicated with '**++**' or '**+++**'), but the source itself may only comprise a small fraction of overall supply chain emissions.

Economic viability of options is signalled by '**$**', '**$$**', or '**$$$**' (or '○' for measures that provide no economic incentive to farmers on their own); '**$**' implies a small economic benefit, '**$$**' implies a more substantial, measurable improvement in economic performance, and '**$$$**' implies a major economic gain from successful implementation. As for mitigation potentials, actual economic implications will vary between regions and even individual farms depending on their baseline performance and management, regulatory context, and access to information, technology, supply chains and markets. Sustainability implications of individual options are indicated by single arrows (↑ benefit, ↓ trade-off, ↕ potential for both benefits and trade-offs).

Every intervention area concludes with a summary of next steps, drivers for success and barriers to implementation, and the economic outlook. Selected examples of current implementation of various mitigation options and key research programmes are given at the end of this publication, along with a list of key references for ***Further Reading*** and a ***Glossary*** of key terms.


Summary of Options
Feed & Nutrition
Genetics & Breeding
Rumen Modification
Animal Health
Manure Management
Grassland Management
Discovery
Proof of Concept
Pilot Study
Best Practice
Feed & Nutrition
Animal Genetics & Breeding
Rumen Modification
Animals & Feed
Grassland Management
Animal & Farm System Managment
Manure Management
Animal Health
Transferring the microbiome of low-methane producing ruminants
Finding new traits for GHG emissions
Vaccines to reduce methane production in the rumen
Selecting for low-methane producing ruminants
Improved performance on low-quality feed
Increase disease resistance
Inhibitors
Carbon sequestration
Feed supplements
Precision feeding
Storage cover
Dietary improvements & substitutes
Efficient & robust animals
Improving forage quality
Manure deposition & application
Capturing biogas from anaerobic processes
Increasing productive lifetime of animals
Grazing practices
Pasture management
Temperature & aeration of manure
Prevention, control & eradication of diseases
Collection & storage facility

Key opportunities for immediate action: summary

Emissions of GHGs in livestock systems imply losses of nitrogen, organic matter and energy, decreasing the overall efficiency of the sector. Increasing overall productivity and efficiency of farm systems, and recovering energy and nutrients, are key strategies to reduce the emissions intensity of livestock systems. The main drivers for this increased efficiency are generally economic benefits and increased resource utilisation, with reduced GHG emissions intensity usually being an indirect benefit. Such existing trends can be accelerated by the increased adoption of current 'best practice' across a wider number of farms which elevates 'average' productivity and efficiency.

This summary highlights four key currently available approaches for reducing on-farm livestock GHG emissions intensity: two options specific to ruminants (improving feed quality/digestibility, and precision farming) and two options that are applicable to both ruminant and monogastric animals (improving animal health and husbandry, and manure management). Note that for specific farm systems and contexts, other specific mitigation options may also be effective and relevant. In addition, improving overall energy efficiency is a general and often cost-effective option, but reductions of total on-farm emissions are generally small except in some intensive and industrial-scale production systems, or when coupled with on-farm biogas production and energy generation.

Improving feed quality and digestibility

All ruminant systems

Low-quality and low-digestibility feeds result in relatively high enteric emissions per unit of meat or milk, particularly in systems with low productivity. Improving feed digestibility and energy content, and better matching protein supply to animal requirements can be achieved through better grassland management, improved pasture species, changing forage mix and greater use of feed supplements to achieve a balanced diet, including cropping by-products and processing of crop residues. These measures can improve nutrient uptake, increase animal productivity and fertility, and thus lower emissions per unit of product, but care needs to be taken that emissions from off-farm production of supplementary feeds and/or processing do not outweigh any on-farm reductions. *Chapter 1 (Feed and Nutrition)*

Improving animal health and husbandry

All systems

Increasing herd and animal efficiency can be achieved by improving herd and animal health management, extending the productive life of animals, and improving reproduction rates to reduce the number of animals kept for herd maintenance rather than production. Reducing the prevalence of common diseases and parasites would generally reduce emissions intensity as healthier animals are more productive, and thus produce lower emissions per unit of output. However, the mitigation potential from health interventions remains poorly quantified, largely due to limited disease statistics and barriers to the adoption of existing disease control mechanisms. Education and availability of efficient animal health diagnostic tools and therapeutics are a key part to improve animal (and human) health. These measures can increase productivity, reduce mortality rates, and reduce the age of first reproduction and replacement rates. *Chapter 4 (Animal Health)*

Manure management: collection, storage and utilisation

All systems involving confinement or housing

Manure collection and storage is often poor and valuable resources contained in manure are lost. Improved manure storage facilities – with proper floors and coverage to prevent run-off to the surrounding environment – and customised technologies to apply manure would enhance production of food and feed crops. In addition, improved manure storage improves the hygienic conditions for animals and humans and enables the recycling of nutrients. Feeding a balanced diet to meet animal protein needs strongly influences manure composition and, depending on existing limitations or surplus of nitrogen in the feed supply, can reduce manure emissions and/or improve animal productivity. Biogas capture and utilisation from manure ponds can provide a cost-effective low-carbon energy source and support energy access in remote rural areas, depending on herd size, housing system and initial capital investment costs. *Chapter 5 (Manure Management)*

Precision livestock farming

Moderate to intensively managed ruminant systems

Precision livestock farming caters for the individual animal's needs in bigger herds, integrating health, genetics, feed, social behaviour and resource use and availability, which can be supported by sensor technology integrated in monitoring systems. Precision application of fertiliser and irrigation, aided by remote sensing of soil moisture, pasture growth and quality, can improve resource use efficiency. Precision livestock farming thus builds on and extends the individual approaches of optimising feed quality and digestibility, and animal health and husbandry. For some farms, reducing overstocking can deliver higher quantity and quality of feed and health care and thus increase productivity of individual animals, which can maintain overall farm profitability while reducing absolute emissions and emissions intensity. *Chapter 1 (Feed and Nutrition)* and *Part 3*

Feed and Nutrition

Feed and nutrition directly affect an animal's productivity and health status and can strongly influence GHG emissions per unit of product. Low digestible feeds affect nutrient uptake and result in low animal productivity. For ruminants, a large fraction of GHG emissions is caused by enteric methane production in the rumen. While total enteric emissions might be lower with low digestible feed, so is overall production; as a result, emissions intensity tends to be much higher. There are multiple ways in which feed quality and digestibility can be improved in all production systems. Feed substitutes and supplements are highly effective ways to increase resource efficiency and change fermentation processes in the animal to decrease GHG emissions intensity, but upscaling such approaches in some instances may conflict with food security if crops are used to feed animals instead of humans directly. Emissions across the feed production chain also need to be quantified to avoid reductions in one area being negated by increases in another.

Improving forage quality

Best Practice Available Now

Forages are feeds with a high variation in composition. In ruminant farming systems using poor quality feed (such as straw, crop residues, or dry fodder), forage processing can effectively improve digestibility of the diet and improve animal productivity at the same time. Systems using coarse straws from millet, sorghum and corn/maize have better feeding quality than slender straws (rice, wheat, barley). Grazing management and improving forage quality by changing forage species can equally contribute to a proper diet formulation in extensive systems, which can substantially increase feed efficiency and production; reductions in emissions intensity of 30% are considered possible in systems that currently use very low-quality feed. See also mitigation options related to ***Grassland Management.*** However, indirect emissions from off-farm feed production need to be considered before net GHG benefits can be determined.

Mitigation potential: ++ - +++ *(estimated up to 30% in systems with poor quality feed)*
Economics: $ - $$$ *(constraints: knowledge, supply chains, labour)*
Sustainability: ↑ *(resource efficiency, food security, livelihoods)*

Dietary improvements and substitutes

Feed substitutes can change fermentation processes in the rumen and influence methane production. Feeding corn or legume silages, starch or soya decreases methane production compared to grass silages. Brassicas (e.g. forage rape) have also shown to reduce methane emissions in sheep and cattle, although with varying implications for productivity. Combining maize and legume silage also reduces nitrogen (N) excretion in urine which can have both GHG and water quality benefits in some systems. Corn/maize and legume silages often increase feed intake and production in dairy cows as compared to grass silages. However, the GHG mitigation effects of replacing grass by other forages need to be considered over the whole supply chain, taking into account changes in land use, emissions from crop production, resilience to climate and market variability, fertiliser inputs and net impacts on regional food security via land-use and food prices.

Mitigation potential: **+ - ++** *on animal level*

Economics: **$ - $$** *(depending on cost of substitutes and alternative land uses)*

Sustainability: **↕** *(reduced N losses, climate resilience; land-use change, food security)*

Feed supplements

Concentrate feeds and starch generally provide more digestible nutrients than roughages, which increases the digestibility of feed and generally lifts animal productivity. The suitability of this approach for GHG mitigation depends on the access to and availability of feed and potential competition with direct human consumption. Feeds for effective mitigation practices include lipids (from vegetable oil or animal fat) and concentrate feed supplementation in mixed and intensive systems. By-product feeds with high oil contents, such as distiller grains and meals from the biodiesel industry, can be cost-effective lipid sources. Lipids seem to increase feed efficiency, but their effect depends on feed composition and the effect is limited on pastures; the (long-term) effects on productivity and product quality need further research. Similarly, adding nitrate to the diet results in lower methane emissions since it is converted to ammonium (NH_4^+) which leaves less hydrogen available for methane production. This approach may have applicability in places such as Australia and Brazil where nitrate could replace the urea which is added to low-quality diets to improve nutritive value. Toxicity issues are however a concern, and more information is needed on the practicalities of this approach.

Mitigation potential: **++**

Economics: **$** *(depending on input costs)*

Sustainability: **↕** *(resource efficiency; animal and food safety)*

Feed and Nutrition: Phases of Maturity

Precision feeding

Precision feeding is about getting the right nutrient to the right animal at the right time. The animal's need changes during their lifetime and cycles of reproduction. Understanding an animal's need on a daily basis can result in major resource efficiency gains. Although direct mitigation effects are uncertain and hard to predict, precision feeding will increase feed efficiency and productivity and consequently can improve farm profitability. Customised balanced feeding programmes in grazing dairy cattle systems have shown to increase productivity and reduce enteric methane emissions intensity (15-20%) and also N excretion (20-30%), which results in reduced emissions from manure. Precision feeding, which combines genetics of the animal with feeding and grazing management, requires advanced technological facilities to precisely monitor the animal's needs and manage pastures and forage production appropriately, and can be rolled out in high-value farm systems that use highly technological farming systems.

Mitigation potential: ++ *(greater potential in lower intensity systems)*

Economics: $ *(subject to access to technology and high product value)*

Sustainability: ↑ *(resource efficiency, reduced N losses)*

Main drivers for success:

The financial benefit of increased animal productivity is the main driver for success. Knowledge and understanding of feed quality and the animal's need is required, as well as the availability of (or ability to change production systems to grow) sufficient quantity and quality of feed. This may require increased information and skills at the farm level and the ability to change and/or develop supply chains. Some options may only be feasible for high value products that generate reliable returns on investments.

Barriers for implementation:

Precision feeding requires investment in new technologies, capital, knowledge and different management practice. Access to information and up-skilling of farm managers may be limited and rely on knowledge transfer and training programmes; successful implementation can also depend on adequate supply chains and infrastructure. Costs of feed substitutes and supplements, and technologies to support precision feeding, may counteract economic benefits from increased productivity. Use of some feeds with multiple roles in food production could negatively affect regional food security through land-use changes and food prices, and increase indirect emissions off-farm. Some feed supplements could alter milk constituents and thus jeopardise the ability to meet market requirements.

Relevant farming systems:

Increasing forage quality and feed substitution is applicable mainly in low-yielding extensive and mixed systems; feed supplements and precision feeding are more likely to be relevant in intensive systems, or high-value grazing systems with intensive management.

Economic outlook:

Investments will generally improve resource efficiency and increase productivity but can expose farmers to increased risk from volatility in input and product prices. Return on investments of feed substitutes and supplements, and on investments in precision feeding systems are highly dependent on product prices and can change over time.

Next steps:

Identification of regionally appropriate packages of mitigation options suitable for specific farming systems. Support for knowledge transfer, adequate training and education. Support to create customised feeding programmes and feed supply chains, which main in turn rely on stable market conditions and commodity prices.

Animal Genetics and Breeding

Improving resource efficiency of animals (reducing input/output ratio) and selecting for animals with lower GHG emissions per unit of feed intake are two main aims by which breeding and genetics can contribute to mitigating GHG emissions. Breeding and genetics developments rely on research involving selection and use of animals having identified desirable traits. Once improvements in targeted traits are achieved,

these superior genotypes can be considered 'best practice' and are ready for on-farm use. The duration required to scale up is dependent on the gestation and fecundity of the animal and replacement rates. Additional refinements and selection may be required to ensure that the animal is adapted to specific environments. New approaches, such as genomic selection, accelerate the selection to implementation stage. Having higher genetically bred animals does not automatically result in higher productivity since adequate feeding and management strategies are needed to realise the full genetic potential of the animal.

Efficient & robust animals

Best Practice
Available Now

Breeding and reproduction organisations focus more and more on breeding efficient and more robust animals: animals consistently able to increase their output per unit of input due to being less susceptible to diseases and changes to their environment and management. Farmers can now ask breeding organisations to label their products in terms of resource efficiency, vulnerability to disease or stress, and adaptability to different climates. Voluntary codes of good practice for breeding organisations exist in Europe. The benefits are permanent and, over time, cumulative: genetic improvement currently accounts for 0.5 % to a 1% efficiency increase per animal per year. Targeted breeding programmes can further increase this, but the appropriateness of specific breeds, their mitigation potential, and any trade-offs with other breeding objectives will depend on the context and farming system.

Mitigation potential: **+ - ++**
Economics: **$ $** *(constraints: investment cost, availability in some regions)*
Sustainability: **↑** *(resource efficiency, increased resilience)*

Improved performance on low-quality feed

Pilot Study
2-5 Years

Animal feed production and feeding accounts for a major part globally of the GHG emissions associated with livestock production. Most animals perform better on high-quality feed although current research is identifying traits for selecting animals that show excellent performance on lower quality feed. Once identified, breeding organisations can select these animals for their breeding and reproduction programmes and bring them to the market. It is estimated that within five years, monogastric animals will be available for the market that perform excellently on low quality feed. For cattle, this is estimated to take 8-10 years. This development is useful for both the intensive livestock industry as it allows changes to existing feeding regimes, and extensive systems reliant on lower quality feed.

Mitigation potential: **+** *(depending on changes in feed regime)*
Economics: **$$** *(constraints: investment cost, availability in some regions)*
Sustainability: **↑** *(resource efficiency, food security, livelihoods)*

Selecting for low-methane producing ruminants

Animals vary naturally in the amount of methane they produce. Selective breeding of animals with low methane emissions per unit of feed consumed could result in a permanent methane reduction of about 10%, with no negative impacts on productivity recorded. Breeding for this requires cheap and practical methods for the identification of animals with the low emissions trait. For sheep, selection via genomic markers is well advanced. Similar work is underway for cattle, with a time-scale of 5-8 years expected to identification of breeding traits and testing for the absence of any penalties on productivity. One of the key challenges is to screen sufficiently large numbers of animals to estimate the heritability and breeding value of the trait and avoid restricting the breeding pool for general genetic improvements of the overall herd. Large-scale breeding systems are not currently available in all regions, and testing to avoid negative side effects on disease resistance, productivity or reproduction is critical.

Mitigation potential: + - ++

Economics: ○ *(additional incentives needed in the absence of productivity benefits)*

Sustainability: ○ *(limited sustainability benefits or trade-offs in themselves, compared to existing animals)*

Finding new traits for GHG emissions

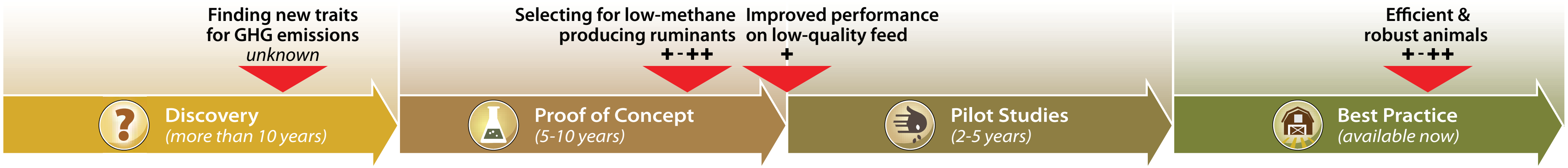
Any variation in emissions among individual animals raises opportunities for breeding and selection programmes to select for lower emitting animals; these are already being researched. Other factors influencing the animal's emission have their basis in the composition of the microbial ecosystems in the stomach and the anatomy of the stomach. For example, early life feeding strategies might have a long-lasting influence on the rumen microbial composition and hence methane emissions over the productive life of an animal. The potential for changing the rumen microbial composition in lambs and calves after weaning towards lower methane production in adult life is currently being explored.

Mitigation potential: *as yet unknown*

Economics: *as yet unknown*

Sustainability: *as yet unknown*

Animal Genetics and Breeding: Phases of Maturity



Main drivers for success:

Breeding organisations in many world regions are constantly working on improving their breeds and adapting them to local environments. Market demand can incentivise the search for traits that improve resource use efficiency. Close cooperation between agri-food industry, breeding organisations and research institutes is beneficial to support this development. Prioritisation within national and international research & innovation initiatives aiming to mitigate GHG emissions is also essential.

Barriers for implementation:

The R&D path in breeding and genetics can be rather long, and the effects of investments may not be evident for several years. A critical challenge is to develop rapid measurement techniques to identify the traits of interest. Even if there are no penalties on productivity, if only a small number of animals having the desired trait can be identified, this would restrict general progress in genetic improvements and creates an implicit economic cost to their incorporation in breeding indices. Evaluation of genetic merit can be difficult as actual production outcomes depend not only on the animal itself but also on animal nutrition and management practices.

Relevant farming systems:

Improved breeds can have substantial impact on all farming systems although relevant types of breeds will differ between systems and regions. Adoption will be challenging in very extensive systems, with limited potential to incorporate breeding options and in regions without dedicated industry bodies that support breeding programmes.

Economic outlook:

Resource efficient breeds are more cost-efficient for the farmer, but upfront costs for research and breeding programmes are high and have a long return on investment. Market demand is crucial, and the ability to access and purchase new and appropriate breeds may require support in some world regions, particularly for small-holders.

Next steps:

Besides finding new traits, the main driver of success will be the incentive for breeders to include mitigation of GHG emissions as a target in their breeding programmes. Engagement options for agri-food industry are to improve interaction between breeding organisation, end-users and the marketplace (including any incentives from governments), early investments in new programmes to encourage this, and exploring opportunities to create incentive packages for farmers to adopt breeds with lower emissions intensity.

Rumen Modification

The rumen and reticulum (reticulo-rumen) make up the largest compartment of a ruminant's stomach. In this part of the stomach, micro-organisms ferment plant materials and provide the animal with energy and nutrients. In this process a specialised group of micro-organisms, commonly called methanogens, produce methane. Rumen modification strategies focus on manipulating methanogens and/or other micro-organisms in the rumen involved in methane production. Increased understanding of the microbial ecosystems in the rumen of different animals kept under a variety of management regimes is required to support such approaches.

Fundamental understanding of the microbiome and the relation between host animals, methanogens and other micro-organisms is essential to be able to modify the rumen in a way that is consistent with farming practices, economics, and food safety requirements. Supportive research is working on mapping the microbial landscape in the rumen, including genome sequencing and improving the taxonomy of rumen microbes, and understanding the diversity of and differences in rumen microbial communities across individual animals *(see also Animal Genetics and Breeding)*, across species and under different management and feeding regimes. A key advantage of rumen modification approaches is their potentially very wide applicability, ranging from extensive grazing to highly intensive farm systems.

Inhibitors

Proof of Concept
5-10 Years

Some chemical compounds can have an inhibitory effect on methane-generating rumen micro-organisms. Laboratory experiments have shown methane reductions in vitro of up to 100%. Some substances have also been demonstrated to be effective in animal trials, with some substances resulting in almost complete removal of methane emissions; however, these are not commercially viable due to animal health and food safety concerns or prohibitive costs. Research is focussed on examining natural or synthetic compounds that meet the requirements of long-term efficacy (including possible adaptation of the rumen microbial community), no negative effects on productivity, and food and animal safety. Once successful inhibitors have been identified, vetting by the regulatory review process could still take several years. Inhibitors could be delivered in animal feed, water supply, mineral lick, drench or bolus, and thus could be tailored to different farm systems.

Mitigation potential: + - ++

Economics: ○ *(depending on commercial cost of inhibitor and production benefits)*

Sustainability: ↕ *(ensuring no negative side-effects and residues in food will be critical)*

Vaccines to reduce methane production in the rumen

A potentially practical and efficient option to reduce methane emissions is to modify the rumen microbial ecosystem via vaccines that would stimulate the host animal to produce antibodies against methanogens. Applying a vaccine would require virtually no change in farm practice, would be applicable to a wide variety of production systems and could complement other mitigation strategies. Current research is targeted at identifying and selecting antigens that can stimulate antibody responses to the methanogens present in the rumen. In parallel, optimal adjuvants are being identified that enhance the immune response to these antigens, so that prototype vaccines are available for testing. The aim is to develop cost-effective vaccines that reduce methane from enteric fermentation without reducing, but possibly even enhancing, productivity. In vitro experiments have achieved emissions reductions of 30%, but such results have yet to be achieved in the complex and evolving ecosystem of the rumen of live animals. This is a fast developing area, which is focussed on achieving a proof of concept in animal trials by mid-2015.

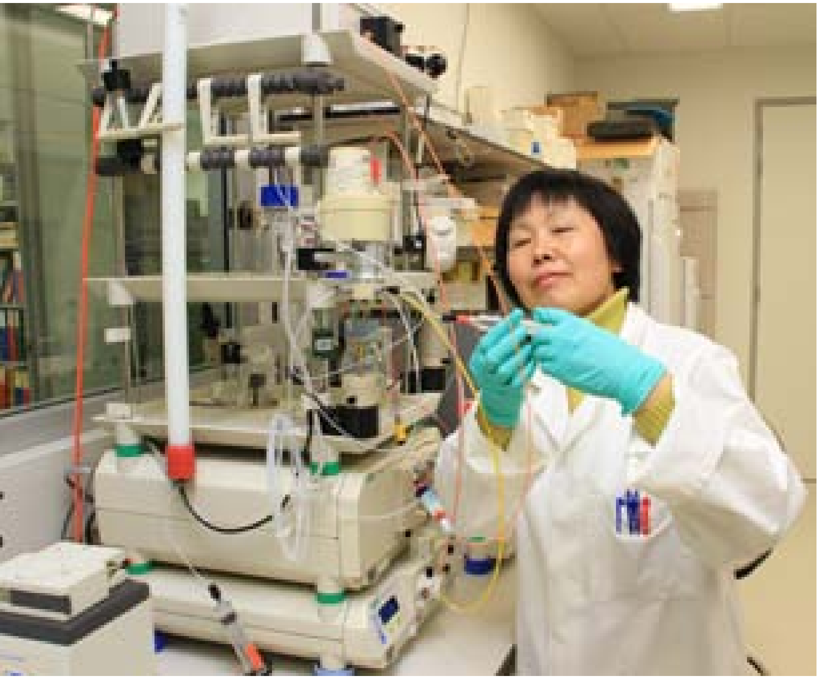
Mitigation potential: *as yet unknown*
Economics: *as yet unknown*
Sustainability: *as yet unknown*

Transferring the microbiome of low-methane producing ruminants

A possible future intervention is transferring the microbiome of low-methane producing ruminants to the rumen of high-methane producing ruminants. This has proven to result in a direct reduction in methane emissions. The difference between low-methane producing ruminants and high-methane producing ruminants can account up to 13-17% between individual cattle. However, this reduction in methane production is not permanent: after a while, the level of emission returns to pre-transfer levels. Better understanding of the cause of the returning high methane production can help to further develop this mitigation measure. This requires exploring the effects of host-microbiome relations, which determines the microbial population in the rumen. There are some indications that interventions in early life may result in more stable changes in the rumen microbial composition, and related work explores the ability to influence this during key dietary transitions (e.g. during weaning and changing dietary fibre content after weaning; ***see also section Animal Genetics and Breeding***).

Mitigation potential: *as yet unknown*
Economics: *as yet unknown*
Sustainability: *as yet unknown*

Rumen Modification: Phases of Maturity



Main drivers for success:

Methane from enteric fermentation presents a net loss of energy to the animals; successful vaccines and inhibitors could therefore allow substantial emissions reductions even while increasing productivity, although this potential productivity benefit has not been demonstrated in practice yet. The ability to translate new knowledge into commercially available measures will depend on development of proof-of-concept and a sufficiently large market, which could be supported by market opportunities associated with low-emissions production systems.

Barriers for implementation:

The development costs of vaccines and inhibitors, including regulatory hurdles and time required to their commercial availability, are high. The public acceptance of vaccines and of (at least some) additives, and demonstration of the absence of any residues in food products, will be critical. Rumen substitute microbial mixture could be regarded as a "probiotic" and hence face restrictions in some markets or consumer segments.

Relevant farming systems:

All ruminant farming systems, although delivery may be easier in confined systems.

Economic outlook:

Effects on animal productivity will be further researched. Development costs for vaccines and willingness to pay for them by end-users need to be considered. In the absence of productivity benefits, adoption of most of these solutions would rely on other incentives such as market opportunities, subsidies (e.g. by integrating them with other standard animal health treatments) or GHG emissions pricing.

Next steps:

Rumen modification is still mostly at the discovery phase, although it is a promising and fast developing area due to the potentially wide applicability of successful solutions and the increasing availability of technologies to handle genetic data. Early industry participation in the development of vaccines and inhibitors, with appropriate management of intellectual property, would support early investment for commercialisation and ensuring consistency of solutions with wider market objectives.

Animal Health

Livestock health is an important aspect of animal welfare, food safety, human health, and production efficiency. Healthy animals are more productive and hence use more of their feed to generate the desired products. Unhealthy animals tend to have a lower productivity resulting from reduced growth and performance, lower reproductive success, and increased need for treatment, resulting in higher emissions per unit of animal product. Improving the animal health status thus offers the opportunity to improve emissions per unit of animal product, while also improving productivity, with important positive consequences for food security, animal welfare, food safety and public health.

The World Organisation for Animal Health (OIE) estimated that globally, on average, 20% of animal productivity losses are attributable to animal diseases. Increased mortality, decreased fertility and decreased productivity from diseases and parasites imply increased emissions intensity at both animal and herd levels, but the effects of potential improvements in animal health and welfare on GHG emissions in the total livestock sector have not yet been examined comprehensively. In the UK, a study estimated the direct costs of cattle diseases on production and productivity loss at £274m (based on three diseases), and that improved animal health measures in dairy cattle could substantially reduce emissions.

Better quantification of the effects of animal health and welfare on GHG emissions intensities is hampered by the lack of data on disease incidence. Some diseases remain prevalent even in developed countries despite their well-documented effects on productivity and the availability of seemingly cost-effective control measures, indicating various barriers to enhanced disease control.

Ensuring adequate feed and nutrition is a key underlying principle to reducing the susceptibility to a range of diseases. Similarly, ensuring proper animal welfare standards are maintained has a strong link with animal health, susceptibility to diseases and herd productivity.

Common diseases

Relevant diseases can include infectious diseases, parasitic diseases, and production or husbandry related diseases (e.g. mastitis or lameness). Some animal diseases are highly specific to regions and production systems. Regional distribution of some diseases may shift as a result of climate change, and enhanced measures to address them could offer multiple climate-related benefits in terms of reducing emissions and adapting to the impacts of climate change. The mitigation benefits of improved control of any disease will depend strongly on their impact on productivity and the availability and costs of treatments. In general, the focus is likely to be the enhancement of animal productivity, including reproductive success where relevant, or reduced risks to food safety or human health, with lower GHG emissions intensities a co-benefit of disease control.

Prevention, control & eradication of diseases

Best Practice Available Now

Prevention as well as early detection of animal diseases and early treatment is key in improving animal health and productivity, reducing mortality and morbidity, and preventing further outbreaks. Education, use of veterinary services, proactive herd health planning, and availability of efficient animal health diagnostic tools and therapeutics are key parts of this, but access to such tools and services remains highly uneven across the world. Improving farm biosecurity measures are important to protect the farm from incoming diseases as well as to help prevent outbreaks of diseases to other farms. An overview of global animal health status is provided by the OIE World Livestock Disease Atlas. The online database *Discontools* currently describes over 50 animal diseases, and the diagnostics and vaccines available. It also indicates the diseases that require development of new diagnostics and therapeutics.

Mitigation potential: **++** *(but lack of detailed estimates)*

Economics: **$ - $$** *(depending on cost of treatment and productivity impact)*

Sustainability: ↑ *(animal welfare, resource efficiency, food security, livelihoods)*

Animal Health: Phases of Maturity

Increasing productive lifetime of animals

For some parts of the livestock sector, extending the productive lifetime of animals will decrease the total GHG emissions per total product over the animal's lifecycle. Relevant approaches include improved conception rates, earlier time of first reproduction and increasing reproductive lifetime, and adjusting overall lifetime to minimise overall GHG emissions per unit of product (which implies increasing longevity for dairy cows, but also reducing time to slaughter for beef cattle through higher growth rates). This can be achieved by breeding and selection, improved feeding, and wider animal husbandry practices to prevent decline in productivity and involuntary or premature culling of sick or underperforming animals. Benefits of extended lifespan of dairy cattle may be limited where the dairy herd provides input to beef production.

Mitigation potential: **+ - ++** *(depending on baseline conditions)*

Economics: **$** *(depending on baseline conditions)*

Sustainability: **↑** *(animal welfare, resource efficiency)*

Increasing disease resistance

Increased disease resistance directly improves animal health and can thereby increase production efficiency and reduce GHG emissions in livestock production. Animal health genomics is an upcoming field which incorporates animal health traits into breeding and reproduction programmes and can ensure that disease resistance does not imply productivity costs. Resistance to some animal diseases is heritable, and consequently, can be criteria for breeding and selection. Examples are mastitis and bovine leukaemia in cattle, foot rot in sheep and salmonellosis in poultry and cattle. A number of successful examples in poultry and pig breeding have substantially decreased disease susceptibility, and advanced genetic techniques offer additional potential.

Mitigation potential: **+** *(but still at proof of concept phase)*

Economics: **$ - $$** *(depending on cost of improved breeds and baseline disease levels)*

Sustainability: **↑** *(animal and human welfare, livelihoods)*

Main drivers for success:

Productivity and economic benefits will likely remain the main drivers for improved animal health. However, making the link between animal health status and GHG emissions intensity more explicit could help re-direct and coordinate resources from agriculture, development, food security and climate change perspectives.

Barriers for implementation:

Willingness or ability to change farming practices and access animal health measures and services, including upfront investment costs, can be limited and varies strongly across world regions. Awareness of climate benefit of improved animal health status is very limited at present.

Relevant farming systems: All.

Economic outlook:

Improved animal health status will improve animal productivity, but cost-effectiveness of measures depends on baseline incidence of disease, options for disease control and their costs, and expected net benefits.

Next steps:

Increase recognition by industry that animal health status is important not only for production efficiency, welfare, public and food safety but also for decreasing GHG emissions per unit of animal product. Better quantification of the effects of animal health and disease levels on productivity and GHG emissions will be important for a solid business case, as will be education to increase awareness and insight in the costs of animal health measures in relation to economic benefits of increased productivity. Most disease statistics cover death, destruction and slaughter of animals, but data are much poorer or almost absent on the underlying impacts on productivity from non-fatal disease levels. Industry can be engaged by raising awareness, supporting data collection, investing in bio-security measures and the development of new diagnostics and prevention tools, and by developing benchmarks of disease levels and intervention options for farmers.

Manure Management

Manure management includes all activities involving the handling, storage and disposal of urine and faeces from livestock (other than manure deposited directly onto pastures by grazing animals). Sound manure management is important to mitigate GHG emissions, but also offers important benefits for reducing nutrient losses from livestock production systems and reducing other detrimental environmental impacts of livestock production such as air and water pollution. Although manure management accounts for only 10% of total livestock emissions, it offers key and technologically mostly mature opportunities for mitigation that also deliver on other economic, social and environmental objectives, although cost-effectiveness can depend on the scale of operation.

There is extensive experience with manure management in high-technological intensive livestock farming systems. Some of these experiences allow for measures to be transferred to other, high-technological as well as low-technological extensive livestock farming systems. Education and provision of information to farmers is the key to ensuring optimal manure management, as well as national and regional manure policy and an enabling environment with supporting technology.

Manure collection and storage

Collection and sound storage of manure are easy measures in high and low technological systems that can prevent run-off of nutrients into the environment, reduce production of GHGs, and allow for recollection of nutrients and reduction of emissions. For most measures there is a difference between slurry manure and solid manure and this should be taken into account when deciding on action, as well as wider environmental and economic context of farm operations.

Collection & storage facility

Best Practice – Available Now

Housing systems with concrete floors (or possibly hard clay floors) in combination with simple equipment for manure storage prevent run-off of valuable nutrients to the environment and therewith eutrophication of the environment, and improve hygiene for lactating dairy cows. Farming systems using feedlots have significant potential to improve collection of manure and urea, offering the co-benefit of being able to use these nutrients as fertiliser.

Mitigation potential: **+++**
(compared to no storage facility)

Economics: ○ - $ *(investment cost; benefit depends on pollution regulations)*

Sustainability: ↑ *(resource efficiency, reduced pollution, public health)*

Temperature & aeration of manure

Best Practice
Available Now

The temperature of manure influences the amount of methane (CH_4) and ammonia (NH_3) produced through anaerobic digestion, with emissions reduced at lower temperatures (but anaerobic digestion stops at very low temperatures). Management options to regulate temperature will depend strongly on climate system, with options ranging from the location of manure storage systems to the use of natural cooling mechanisms. Aeration of solid and liquid manure can substantially decrease CH_4 and nitrous oxide (N_2O) emissions, with a variety of approaches available for different systems.

Mitigation potential: **+ - ++** *(depending on climate)*

Economics: ○ *(investment cost; limited production benefits)*

Sustainability: ↕ *(aeration can increase NH_3 emissions)*

Storage cover

Pilot Study
2-5 Years

Sound storage should be supported with good cover (concrete, wood or possibly as simple as banana leaves), although implications on emissions are complex and variable as effectiveness depends on cover permeability, thickness, degradability, porosity and management. Semi-permeable covers decrease NH_3, CH_4 and odour emissions, but can increase N_2O emissions. Impermeable covers give the opportunity to flare CH_4 or collect as biogas *(see Capturing biogas from anaerobic processes)*.

Mitigation potential: **++** *(if CH_4 is captured, but possible increase of N_2O emissions)*

Economics: ○ - $ *(investment cost; benefit depends on odour regulations)*

Sustainability: ↑ *(reduced odour emissions)*

Manure Management: Phases of Maturity

Manure deposition & application

Most manure is eventually applied back to soils where it acts as a natural fertiliser. N_2O emissions are greatly reduced if the amount of nitrogen applied through slurry matches the amount needed for optimal pasture growth; this can imply delaying spreading, covering wider areas, and ensuring the nitrogen available from slurry is taken into account when deciding on application of any additional nitrogen fertilisers. Emissions can also be reduced by avoiding manure application on wet soils, and a general shift (where possible) towards application in spring rather than autumn/winter, when pasture growth is low. Urease and nitrification inhibitors have been shown to be effective in reducing N_2O production and also reduce nitrate leaching, with important co-benefits for water quality, though the identification of some inhibitor residues in milk has raised concern about food safety.

Mitigation potential: + - ++

Economics: ○ - $ *(depending on available land and manure storage, and saved fertiliser costs)*

Sustainability: ↑ *(mainly via reduced nitrate leaching)*

Capturing biogas from anaerobic processes

Anaerobic digestion of manure leads to the production of CH_4 as a by-product – producing biogas as a form of renewable energy. Efficient biogas digesters avoid 60-80% of the CH_4 emissions that would have occurred from manure otherwise. Experience with biogas plant installation differs among countries with systems differing in scale depending on the characteristics of the livestock production system. Tailor-made solutions exist in different countries. There are a few side notes that should be considered related to this measure:

- In subsistence farming systems, simple digesters may require support for capital investments but have relatively short pay-back periods especially where access to other energy sources is limited or unreliable.
- Biogas installation requires investment in technological equipment. For industrial-scale biogas digesters used to produce renewable energy for towns, sound infrastructure is needed.
- In regions with high temperatures, fermentation processes go faster and gas production can be high. Many practical initiatives currently focus on providing biogas installations. However, maintenance of such installations and knowledge dissemination is a point for attention. By contrast, in regions with average temperatures below 15°C, anaerobic digesters are not recommended without supplemental heat control, since lower temperatures reduce the production of biogas.

Mitigation potential: +++ *(including avoided fossil fuel emissions)*

Economics: ○ - $$ *(depending on scale; investment cost, but rapid pay-back in many circumstances)*

Sustainability: ↑ *(renewable energy supply, energy access, resource utilisation)*

Main drivers for success:

Manure management techniques are mostly mature technologies, with customised improvements for all systems already available. Transferring the basic principles, education, information, policies and an enabling environment (financial and technical infrastructure) are fundamental to the success of improving collection, storage and application. Especially for small-holders, customised training programmes are needed (in combination with training on health/hygiene, feeding, access to finance, opportunities to share equipment, etc). Broader environmental regulations (for odour and water quality) can be important drivers for adoption of manure management practices, as can be energy access through the use of biogas digesters in remote rural areas.

Barriers for implementation:

Upfront investment in (high and low) technological apparatus and adequate infrastructure can be high and act as barrier. Changing practice requires knowledge and expertise and may need to overcome social and cultural barriers.

Relevant farming systems:

Mixed and intensive system involving housing, or feed/stand-off pads where the manure/slurry can be readily collected in appropriate volumes.

Economic outlook:

Most intervention options require investment in knowledge, facilities and changes in practices. Except for biogas production and possible recycling of nutrients, these measures are not directly turned into economic benefit, except where they help to meet other environmental/regulatory constraints relating to air and water quality. However, better storage and utilisation of manure in extensive small-scale farming systems (or on household level) can improve productivity, food security and livelihoods. It also has many hygienic benefits and will improve the overall living environment of the farm/household.

Next steps:

Training programmes for small-holders, with financial support systems for biogas installations, subsequent manure storage and application (and training) are required. Early engagement of industry to provide benchmarks for nutrient losses and re-utilisation and demonstration farms would accelerate development and adoption of best practices. In addition, manure contains valuable resources (organic matter, phosphate, nitrogen, micro-organisms, potassium, enzymes). New ways to extract these by-products from manure and bring them back to market are essential to create a more resource efficient system and can serve as further incentives for manure management.

Grassland Management

Grasslands are a huge source of low-cost and high-quality feed for ruminants. They enable ruminants to produce high quality protein for human consumption from land and food resources that are often not in direct competition with other human uses. It is estimated that roughly half of the total dry matter intake by livestock at the global level comes from grass and other roughages, albeit with strong regional variations. Grassland soils also store large quantities of carbon and in many regions have the potential to sequester more carbon, while providing a range of other ecosystem services related to habitat and water quality. Improving management practices and breeding/adopting new species and cultivars can improve the quantity and quality of feed to animals and also, in some regions and systems, enhance soil carbon storage. However, the potential for carbon sequestration and techniques for achieving it are country/region specific, and differ across soil types, management practices and climate.

Grazing practices

In mixed systems, decreasing grazing hours will decrease urinary nitrogen excretion on land and, as a consequence, decrease nitrous oxide (N_2O) emissions. Minimising grazing during the wet months of the year, and avoiding pastures that are above a soil moisture threshold, are most effective as more N_2O is released from moisture saturated soils. However, keeping animals off paddocks can cause increased ammonia (NH_3) emissions due to the mixing of urine and faeces in the stand-off area, with resulting negative impacts on air quality, ecosystem productivity, and human health. Feed pads and stand-off areas also require proper manure management to avoid counterproductive outcomes *(see section Manure Management)*. Introducing a 'combination approach' in intensive systems, where animals graze during the day and are housed during the night can be effective to improve grassland management, feed and nutritional aspects and animal health while also reducing negative impacts from grazing on water quality.

Mitigation potential: + - ++ *(depending on farm system and baseline performance of pastures)*
Economics: ○ *(investment/labour costs; benefits depend on other pressures related to water quality)*
Sustainability: ↑ *(water quality, reduced nutrient losses)*

Pasture management

The quality of grass determines to a great extent digestibility and nutritional uptake, and therefore influences the production of methane (CH_4) in the rumen *(see section on Feed and Nutrition)* as well as animal performance, with positive implications for emissions per unit of product. Improvements in pasture quality through pasture renovation, fertilisation, irrigation, adjusting stock density, avoiding overgrazing (including through fencing and controlled grazing), appropriate rotations, and introduction of legumes are well understood and effective practices that could be spread more widely in currently low-yield grazing systems, although the appropriateness of specific measures will vary between regions. Additional mitigation strategies are being researched:

a) The effects of more targeted use of fertilisers on forage production and quality and the ability to stimulate plant growth through means other than nitrogen (N) supply; plants generally require more N for optimal growth than animals require in their feed, resulting in the excretion of excess N and thus increased N_2O and NH_3 emissions. A key challenge therefore is to combine high yields with lowered N input requirements.

b) The chemical composition of grass when it is consumed by the animal; the sugar content of grasses changes with time of day, season, fertilisation rate and species/cultivar, which may influence CH_4 emissions. An added complication is that the chemical composition of forages may change with changing climate and rising carbon dioxide concentrations in the atmosphere.

Mitigation potential: **+ - ++** *(depending on baseline performance of pastures and N inputs)*

Economics: **$** *(depending on baseline performance, N and water costs)*

Sustainability: ○ *(changes in N inputs and water use)*

Carbon sequestration

Grasslands cover a large area of land and hence play a role in the terrestrial cycling of carbon stocks, and estimates suggest a large potential to offset some of the emissions from animals through increased carbon sequestration in pastoral soils. However, carbon sequestration remains difficult to monitor and verify, is highly variable across small spatial scales, and subject to reversibility/impermanence due to short-term effects of flooding, droughts and wind erosion, and changes in management practice. Despite the considerable uncertainties attached to carbon sequestration as mitigation measure, there are a few robust principles that tend to increase sequestration of carbon in grasslands. Their effectiveness will depend strongly on climate, baseline soil carbon stocks, soil type and management history:

- Adjusting stocking densities to avoid overgrazing, balance between grazing and rest periods; note in some circumstances, this could involve increased grazing
- Sowing of improved grass varieties (e.g. deep rooting grasses and more diverse swards for resilience)
- Restoration of organic soils / peatlands
- Improved use of fire for sustainable grassland management; fire prevention and improved prescribed burning

Mitigation potential: ○ - **++** *(depending on baseline soil carbon stocks, ability to monitor/verify)*

Economics: **$ - $$** *(depending on baseline soil carbon stocks and production levels)*

Sustainability: ↑ *(improved soil function and related ecosystem services)*

Main drivers for success:

Main incentives for sound pasture management and fertiliser use are productivity gains, which will be greatest in areas with low-yielding and overgrazed or unimproved pastures. Monitoring and demonstration of benefits may be difficult in areas subject to large climatic variability or that are under intense overgrazing pressure. Appropriate combinations of practices need to be tested to ensure they are compatible with local farm systems, access to information and skilled labour, climate and soil conditions.

Barriers for implementation:

Improved grassland management requires a change in practice, which relies on education and training. Willingness to change grazing practices may be limited due to cultural reasons, existing economic pressures or regulatory uncertainty and land tenure systems. Soil carbon sequestration options are hard to measure and verify, with very sparse data and knowledge in some world regions, and the benefits can be quickly reversed with changing climate conditions or management practices.

Relevant farming systems:

All grazing systems.

Economic outlook:

Changes in pasture management normally do not have high capital costs. However, indirect and implicit costs in terms of skilled labour, training, confidence in economic return from changed practice, and access to information can be significant. Economic benefit can be substantial where baseline performance of pastures and/or existing soil carbon stocks are low, but benefits can take several years to accumulate and require on-going management to maintain them.

Next steps:

There is a high potential to transfer best practices from some world regions and farm systems to others, subject to suitable modifications, to lift pasture performance. Industry engagement could support the testing and implementation of customised grazing schemes to support regional development and broaden supply chains.

Grassland Management: Phases of Maturity

Advancing low-emissions farm systems

Existing studies indicate a significant global potential for greenhouse gas (GHG) mitigation in the livestock sector. In many situations, increasing animal productivity and overall farm system efficiency is one of the most effective mitigation strategies. This document has described a range of specific options to reduce on-farm GHG emissions in animal production. Realising this potential depends on the overall management of farm systems to integrate different mitigation options that deliver climate and other environmental benefits while providing for economic, social and cultural goals of farmers. Industry can support those efforts through incentives and technical support for implementation of best practices as well as through engaging in the development and testing of emerging solutions.

Increased efficiency: a common goal with many different realisations

Animal and farm management practices differ greatly between production units and within production systems. Agro-ecological conditions (including soil types and climate), farming practices and supply chain management explain much of this variation. A recent study by FAO estimates that if all producers in a given system, region and climate achieved the production efficiency of the top 10 or 25 percent of producers, total emissions could be reduced by 18-30% if overall production remains the same. Alternatively, total animal production could increase by similar amounts without attendant increase in GHG emissions.

While intensification can bring both economic and environmental benefits, and contribute to overall food security through increased production, it can also result in trade-offs with other goals. Examples include increased nitrate losses to water ways, odour, resource losses, and concerns regarding animal welfare. Some strategies to increase efficiency could also increase the exposure of farmers to climate and market volatility, e.g. where significant investments and systems changes would be required that rely on tightly managed financial or resource flows.

A key for success is to find ways for sustainable intensification that offer multiple-win solutions on economic, climate, environmental and social aspects of animal production. The best practices and emerging mitigation options presented in the previous chapters can serve as parts of a puzzle, but generally require tailor-made solutions to ensure they are appropriate to particular regional and system-specific circumstances. The challenge is to take a systems approach when deciding on action, and to recognise the interdependence of mitigation options to achieve overall gains in farm management.

Integrating mitigation measures: from farm management to precision livestock farming

An example of a holistic approach at the farm system level is the concept of precision livestock farming. Precision livestock farming is about catering for the individual animal's needs. Animal needs change over time for the quantity and composition of feed and health care. Production efficiency, and thereby the amount of GHG emissions per animal product, is influenced by the extent to which these needs are fulfilled. The key options depend on the underlying farm system, but they inevitably present a package of individual options.

For lower-yielding, extensive systems, solutions will generally focus on better adapted breeds, grazing management, dietary supplementation, balanced feed programmes and improved attention to animal health, welfare and reproduction. For intensive high-technological and high-value systems, there is the opportunity to use sensor technologies to better integrate and monitor health, genetics, feed, social behaviour, resource use and availability and emissions.

In some contexts, de-stocking and diversification of rural land-use can be viable solutions to achieve environmental goals and maintain viable farming communities, even if total production may be reduced. Reducing the number of animals in a herd can result in higher provision of feed and health care per animal, resulting in increased productivity per animal and hence reduced emissions intensity. Choices and options will generally depend on broader economic and social trends and policy settings, as well as projected impacts of climate change, and thus be highly regionally and even location-specific.

Realising opportunities

Even though increased productivity is expected in many cases to deliver net economic benefits to farmers, realising these opportunities is not easy. Adopting more efficient technologies and practices relies on a mixture of incentives, access to knowledge, technology, stable supply chains, and access to skilled labour and investment finance. Changing farm management systems also requires an ability and willingness to manage risks associated with such changes, including those related to significant investments in the context of volatile markets, changeable environmental regulations, and shifting societal expectations on farmers and farming.

In some farming systems, especially in lower-income countries, livestock also serve functions other than food production (capital, safety net, insurance, social status, manure production for fertiliser) and these need to be taken into account when intervention options and strategies are being considered. The optimal mix of mitigation options that are consistent with broader development objectives and market demands, and critical challenges in implementing these options, varies significantly between regions and generally requires active work with producers and their supply chains to uncover key barriers and ways to overcome them.

Options for industry to foster efficient, climate-smart agriculture

Industry can foster locally appropriate pathways to increased efficiency and reduced emissions intensity of livestock food production, and many options are already being supported through various industry-led initiatives. A non-comprehensive list of possible entry points to increase adoption of best practices includes:

- Supporting regionally appropriate knowledge transfer and dissemination of best practices, including training and education on issues such as animal health, feeding, manure, grassland and forage management.
- Developing customised regional packages of mitigation opportunities:
  - Assessment of regional livestock value chains and identification of potential efficiency gains consistent with farm systems, market demands, regulatory contexts and broader social and cultural development aspirations and practices.

- Exploration of regional and system-specific barriers to efficiency gains and opportunities to address such barriers, such as mechanisms to reduce market volatility, index-based insurance schemes, training and demonstration programmes for farm staff and managers.

- Creating incentives and support farmers to adopt GHG emissions mitigating practices:
  - Develop, disseminate and potentially even require farm-scale tools to estimate GHG emissions alongside production efficiency, nutrient requirements and losses.
  - Promote climate-related market opportunities based on GHG emissions intensity alongside other sustainability criteria, to provide farmers with commercial rewards for low-emissions production.
  - Provide and encourage (regional) productivity and efficiency benchmarks to allow farmers to learn from each other and to continually improve 'current best practice'.
  - Work with intermediaries, such as breeding organisations and feed companies, to explore incentives for the integration of climate-friendly processes and measures along the supply chain.
  - Support finance mechanisms that can help overcome capital investment barriers, and innovation hubs to generate, demonstrate and extend locally relevant practices and technologies.

Apart from current best practices, many further mitigation options are at various stages of research and development, as outlined in this document. Industry can support bringing such emerging solutions to market through a range of measures. These could range from engagement and investment at the discovery end to supporting trials, mechanisms for up-scaling pilot studies, and active commercialisation of new products and technologies with a deliberate view to reduce GHG emissions intensity. Such early engagement would ensure that research is targeted at industry needs and potential solutions fit market constraints and commercialisation objectives, and could create synergies between the expertise and perspectives of the global agri-food industry and academic and on-farm expertise in livestock management, feed production and processing, and animal and microbial genetics.

Ultimately, agriculture that is better adapted to climate variability and change, has a lower environmental footprint and GHG emissions intensity, and supports economic and societal aspirations of farmers, will generate greater and more reliable returns along the entire value chain, and help to ensure food security around the world.

Summary table: mitigation options across different areas highlighted in this report

	Best practice	Pilot	Proof of concept	Discovery
Feed and Nutrition	• Improving forage quality • Dietary improvements & substitutes.	• Precision feeding • Feed supplements		
Animal Genetics and Breeding	• Efficient & robust animals	• Improved performance on low-quality feed	• Selecting for low-methane producing ruminants	• Finding new traits for GHG emissions
Rumen Modification			• Inhibitors	• Transferring the microbiome of low-methane producing ruminants • Vaccines to reduce methane production in the rumen
Animal Health	• Increasing productive lifetime of animals • Prevention, control & eradication of disease		• Increase disease resistance	
Manure Management	• Collection & storage facility • Temperature & aeration of manure • Capturing biogas from anaerobic process • Manure deposition & application	• Storage cover		
Grassland Management	• Grazing practices • Pasture management		• Carbon sequestration	

Further reading

A selection of articles, websites and examples for further reading:

Livestock and climate change overview

Gerber, P.J. *et al.* (2013): Tackling Climate Change Through Livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organisation of the United Nations (FAO), Rome.

FAO (2013): Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO2 emissions. FAO Animal Production and Health Paper No. 177. Gerber, P.J. *et al.* (eds), Food and Agriculture Organisation of the United Nations (FAO), Rome.

Smith, P. *et. al.* (2014): Climate Change 2014: Mitigation. Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU). Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. ***www.mitigation2014.org***

Tubiello, F. N. *et al.* (2013): The FAOSTAT database of greenhouse gas emissions from agriculture (2013). *Environmental Research Letters* 8, 015009. ***faostat.fao.org***

Opio, C. *et al.* (2013): Greenhouse Gas Emissions from ruminants supply chains: A global life cycle assessment. Food and Agriculture Organisation of the United Nations (FAO), Rome.

CCAFS (2014): Big Facts on Climate Change, Agriculture and Food Security. Climate Change, Agriculture and Food Security (CCAFS) Programme of the CGIAR. ***ccafs.cgiar.org/bigfacts2014***

Examples of international initiatives that address GHG emissions from agriculture

Global Research Alliance on Agricultural GHG Emissions ***www.globalresearchalliance.org***

Sustainable Agriculture Initiative (SAI) Platform ***www.saiplatform.org***

Food and Agriculture Organisation of the United Nations (FAO),
- Livestock Environmental Assessment and Performance Partnership ***www.fao.org/partnerships/leap/livestock-partnership***
- Animal Production and Health Division ***www.fao.org/ag/againfo/themes/en/Environment.html***

Global Agenda for Sustainable Livestock ***www.livestockdialogue.org***

Climate and Clean Air Coalition (CCAC) ***www.unep.org/ccac***

Joint Programming Initiative on Food Security, Agriculture and Climate Change ***www.faccejpi.com***

Climate Change, Agriculture and Food Security (CCAFS) Research Programme ***ccafs.cgiar.org***

Climate Smart Agriculture (CSA) ***www.fao.org/climate-smart-agriculture***

Global Methane Initiative (GMI) ***www.globalmethane.org/agriculture***

Assessing on-farm emissions

Colomb, V. *et. al*. (2013): Selection of appropriate calculators for landscape-scale greenhouse gas assessment for agriculture and forestry. *Environmental Research Letters* 8 015029 ***iopscience.iop.org/1748-9326/8/1/015029***

Examples of existing tools:

International Dairy Federation: a common carbon footprint approach for the dairy sector ***www.idf-lca-guide.org***

Cool Farm Tool ***www.coolfarmtool.org/CoolFarmTool***

OVERSEER Nutrient Budgets—on-farm management tool ***www.overseer.org.nz***

Carbon Accounting for Land Managers (CALM) tool ***www.calm.cla.org.uk***

Verified Carbon Standard Methodology for Sustainable Grassland Management (SGM) ***www.v-c-s.org/methodologies/methodology-sustainable-grassland-management-sgm***

COMET-Farm carbon and greenhouse gas accounting system ***cometfarm.nrel.colostate.edu***

Further reading per intervention area

Feed and Nutrition

GRA Feed and Nutrition Network and Database ***animalscience.psu.edu/fnn***

Hristov, A.N. *et al*. (2013): Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *Journal of Animal Science* 2013, 91: 5045-5069. ***www.journalofanimalscience.org/content/91/11/5045***

Garg, M.R. (2013): Balanced feeding for improving livestock productivity: Increase in milk production and nutrient use efficiency and decrease in methane emission. FAO Animal Production and Health Paper No. 173, Food and Agriculture Organisation of the United Nations (FAO), Rome.

Garg, M.R. *et al*. (2013): Effects of feeding nutritionally balanced rations on animal productivity, feed conversion efficiency, feed nitrogen use efficiency, rumen microbial protein supply, parasitic load, immunity and enteric methane emissions of milking animals under field conditions. *Animal Feed Science and Technology*, 179:1-4. ***www.animalfeedscience.com/article/PIIS0377840112003902/abstract***

Cow of the Future: Considerations and Resources on Feed and Animal Management. Innovation Center for US Dairy. ***bit.ly/1At68pf***

FeedPrint: calculates the carbon footprint of feed raw materials ***webapplicaties.wur.nl/software/feedprint***

Feed4Foodure: project to improve nutrient utilisation and socially responsible livestock farming in the Netherlands ***www.wageningenur.nl/en/Research-Results/Projects-and-programmes/Feed4Foodure.htm***

Animal Breeding and Genetics

GRA Animal Selection, Genetics and Genomics Network ***www.asggn.org***

Breed4Food ***www.breed4food.com***

Methagene Research project ***www.methagene.eu***

Hristov, A.N. *et al*. (2013): Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. Journal of Animal Science 2013, 91: 5095-5113. ***www.journalofanimalscience.org/content/91/11/5095***

Chapter Animal Husbandry & Animal Genetics, in: FAO (2013): Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO_2 emissions. FAO Animal Production and Health Paper No. 177. Gerber, P.J. *et al*. (eds) Food and Agriculture Organisation of the United Nations (FAO), Rome.

Rumen modification

GRA Rumen Microbial Genomics Network
www.rmgnetwork.org.nz

RuminOmics EU research project *www.ruminomics.eu*

Animal Health

GRA Animal Health and Greenhouse Gas Intensity Network
www.globalresearchalliance.org/research/livestock/activities/networks-and-databases/#AnimalHealth

World Organisation for Animal Health (OIE) *www.oie.int*

World Livestock Disease Atlas *www.oie.int/doc/ged/D11291.pdf*

Discontools *www.discontools.eu*

Breeding for disease resistance, examples: *www.eadgene.info*

Cow of the Future: Considerations and Resources on Feed and Animal Management. Innovation Center for US Dairy. *bit.ly/1At68pf*

DEFRA (2014): Modelling the Impact of Controlling UK Endemic Cattle Diseases on Greenhouse Gas Emissions. *Defra project AC0120* Department for Environment, Food and Regional Affairs, UK.

Manure Management

GRA Manure Network *www.globalresearchalliance.org/research/livestock/activities/networks-and-databases/#Manure*

Montes, F. et al. (2013): Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. Journal of Animal Science 2013, 91: 5070-5094.
www.journalofanimalscience.org/content/91/11/5070

MacLeod, M., et. al. (2013). Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment. Food and Agriculture Organization of the United Nations (FAO), Rome.

Global Agenda for Sustainable Livestock, Manure management component “From Waste to Worth” – manure management component of the Global Agenda for Sustainable Livestock
www.livestockdialogue.org/focus-areas/waste-to-worth

eXtension: Research-based Learing Network
www.extension.org/animal_manure_management

Example Lao Biogas Pilot Programme Case study
ebookbrowsee.net/carbon-financing-domestic-biogas-in-lao-pdr-barriers-and-drivers-of-success-2009-pdf-d337432035

Grassland Management

GRA Grassland Research Network *www.globalresearchalliance.org/research/livestock/activities/networks-and-databases/#grassland*

Global Agenda for Sustainable Livestock, Grassland management component *www.livestockdialogue.org/focus-areas/restoring-value-to-grasslands*

Verified Carbon Standard Methodology for Sustainable Grassland Management (SGM) *www.v-c-s.org/methodologies/methodology-sustainable-grassland-management-sgm*

Glossary

Entries in this glossary reflect the use of terms in this report. Definitions are based on, but modified if necessary, definitions provided in IPCC (2007 and 2014), FAO (2013) and IDF (2010) reports, and other publicly available sources.

Age at first reproduction

The time spent between birth and first calving (farrowing).

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.

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).

Co-benefit

The positive effect(s) that a policy or measure aimed at one objective might have on other objectives. For example, the primary goal of a change in farm practice may be to increase profitability per hectare, but it may also lower emissions per unit of product.

Cost-effectiveness

The balance between economic gains from and costs of that activity. In the context of climate change, the cost-effectiveness of measures to reduce greenhouse gas emissions can depend strongly on the assumed cost associated with greenhouse gas emissions, and hence the economic benefits from reducing such emissions.

Crop residue

Plant materials left in an agricultural field after harvesting (e.g. straw or stover).

Dairy herd

Consistent with definitions used in other assessments, this includes all animals in a milk-producing herd: milked animals, replacement stock and surplus calves that are fattened for meat production.

Emissions

Release to air and discharges to water and land that result in greenhouse gases entering the atmosphere. The main emissions concerning GHGs from agriculture are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).

Absolute emissions

Total emissions of greenhouse gases resulting from an activity.

CO_2-equivalent emissions

Where several gases are being emitted, absolute greenhouse gas emissions are often expressed in an aggregated unit called "CO_2-equivalent" emissions, or CO_2-eq. CO_2-eq emissions are commonly calculated by multiplying the emission of each gas by its Global Warming Potential (GWP), which is a multiplier that accounts for the different warming effects and lifetimes of non-CO_2 greenhouse gases over a given time horizon compared to CO_2. GWPs are being updated regularly by the Intergovernmental Panel on Climate Change (IPCC). This brochure uses GWPs with a time horizon of 100 years, with values from the IPCC's Fourth Assessment Report issued in 2007. This is also used for reporting of emissions from 2013 onwards under the United Nations Framework Convention on Climate Change.

GWP values are: 1 kg CO_2 = 1 kg CO_2-eq; 1 kg CH_4 = 25 kg CO_2-eq; 1 kg N_2O = 298 kg CO2-eq.

Direct emissions

Emissions that physically arise from activities within well-defined boundaries or, for instance, a region, an economic sector, a company or a process.

Indirect emissions

Emissions that are a consequence of the activities within well-defined boundaries of, for instance, a region, an economic sector, a company or process, but which occur outside these specified boundaries. For example, emissions arising from deforestation to provide land for livestock activities are generally considered indirect emissions, since they do not directly contribute to the operation of the livestock system. By contrast, 'off-farm' emissions usually refer to emissions that occur from production inputs produced outside the boundary of a farm (such as fertiliser or brought-in feed).

Emissions intensity

Total emissions of greenhouse gases resulting from an activity, per unit of product generated by this activity (such as kg CO_2-eq per litre of milk, or per kg of meat). Where a single activity generates multiple products, emissions intensities have to be calculated by allocating absolute emissions from this activity to different products (e.g. milk and meat produced by dairy herds).

On-farm emissions

Direct emissions generated within the boundaries of a farm.

Off-farm emissions

Direct emissions generated outside the boundaries of a farm, but used to support production within that farm (e.g. emissions arising from supplementary feed produced off-site).

Supply-chain emissions

The combination of 'on-farm' and 'off-farm' emissions. Depending on the specific application, supply-chain emissions can also include indirect emissions.

Enteric fermentation

Enteric fermentation is a natural part of the digestive process for many ruminant animals where anaerobic microbes, called methanogens, decompose and ferment food present in the digestive tract producing compounds that are then absorbed by the host animal.

Farm systems

Intensive

Intensive farming is characterised generally by a high use of inputs such as capital, labour, or higher levels of use of pesticides and/or fertilisers relative to land area. In animal husbandry, intensive farming involves either large numbers of animals raised on limited land, usually confined animal feeding operations, or managed intensive rotational grazing. Both increase the yields of food and fibre per hectare as compared to traditional animal husbandry, and are usually associated with higher absolute emissions per hectare but lower emissions intensity. *See also Extensive systems.*

Extensive

Extensive farming is an agricultural production system that uses lower levels of inputs of labour, fertilisers, and capital, relative to the land area being farmed. Extensive farming most commonly refers to sheep and cattle farming in areas with low agricultural productivity, but can also refer to large-scale production systems with low yields per hectare but high yields per unit of labour. *See also Intensive systems.*

Grazing

In a grazing farming system, animals acquire most of their feed from grazing either rangelands or improved pastures. Farm systems where animals graze on rangelands are usually extensive farm systems, whereas farms where animals graze on improved pastures may be referred to as intensive or extensive farm systems, depending on context. Some grazing systems can involve periods of housing depending on climatic conditions. *See also Housed system.*

Housed

In a housed farming system, animals spend most or all of their time in a housed situation , and have feed brought to them. The feed may be produced off-farm (particularly in intensive systems) or on-farm. In partial housing systems, the animals may be in a housing situation only over some periods of the year, or only for parts of the day (e.g. only during the night and/or some feeding periods). *See also Grazing system.*

Feed balancing

The action of selecting and mixing feed materials (e.g. forages, concentrates, minerals, vitamins, etc.) to produce an animal diet that matches animal's nutrient requirements as per their physiological stage and production potential.

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 optimise utilisation by animals (e.g. through drying, grinding, cooking and pelleting).

Greenhouse gases

Greenhouse gases (GHG) are gaseous constituents of the atmosphere (both natural and resulting from human activities) that absorb and emit thermal infrared radiation. A build-up of the concentration of those gases due to human activities causes global average temperature to increase and the climate to change; this is also referred to as the enhanced greenhouse effect. Agriculture is primarily responsible for the direct on-farm emission of two greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), with additional direct on-farm and off-farm emissions or removals of carbon dioxide (CO_2) from changes in soil carbon, energy use, and indirect CO_2 emissions from the production of fertiliser and deforestation.

Inhibitor
A chemical substance that reduces the activity of some micro-organisms. In agriculture, urease and nitrification inhibitors are used to reduce the break-down of animal excreta into nitrate and nitrous oxide in soils, while methane inhibitors are intended to reduce the activity of methane-generating microbes in the rumen of animals.

Mitigation potential
In the context of climate change, the mitigation potential is the amount of emissions reductions that could be – but are not yet – realised over time. In this report, the mitigation potential is given as those emissions reductions that are technically feasible at relatively low costs, but without taking account of barriers that may make it difficult to achieve those emissions reductions in practice.

Monogastric
A monogastric organism has a simple single-chambered stomach, compared with a ruminant organisms like cows, sheep or goats, which have a four-chambered complex stomach. Herbivores with monogastric digestion can digest cellulose in their diets by way of symbiotic gut bacteria. However, their ability to extract energy from cellulose digestion is less efficient than in ruminants. Major monogastric animals considered in this report include pigs and poultry. *See also Ruminant.*

Productivity
Amount of output obtained per unit of production factor. In this reports, it is mostly used to express amount of product generated per unit of livestock and time (e.g. kg milk per cow per year).

Ruminant
Ruminants are mammals that are able to acquire nutrients from plant-based food by fermenting it in a specialised stomach (the rumen) prior to digestion, principally through bacterial actions. The process typically requires the fermented ingesta (known as cud) to be regurgitated and chewed again. The process of rechewing the cud, which further breaks down plant matter and stimulates digestion, is called rumination. Major ruminant animals considered in this report include cattle, sheep and goats. *See also Monogastric.*

Replacement rate
The percentage of adult animals in the herd replaced by younger adult animals each year.

Trade-off
The negative effects that a policy or measure aimed at one objective might have on other objectives. For example, the primary goal of a change in farm practice may be to increase profitability per hectare, but it may result in increased leaching of nitrate into waterways.

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.

Reducing greenhouse gas emissions from livestock:
Best practice and emerging options

Global Research Alliance on Agricultural Greenhouse gases: www.globalresearchalliance.org

SAI Platform: www.saiplatform.org • ***New Zealand Agricultural Greenhouse Gas Research Centre:*** www.nzagrc.org.nz