The Value of Animal Health Innovations for Sustainable Livestock Transformation

HealthforAnimals
global animal health association

With the technical support of:

Food and Agriculture Organization of the United Nations

Required Citation:
HealthforAnimals, 2025, *The Value of Animal Health Innovations for Sustainable Livestock Transformation*

Acknowledgments

We would like to acknowledge all those who contributed to the development of "The Value of Animal Health to Sustainable Livestock Transformation," and specifically:

- Lydia Lanzoni (Livestock and Climate Change Specialist), Dominik Wisser (Livestock Policy Officer), and Junxia Song (Senior Animal Health Officer), Animal Production and Health Division, FAO
- The following members of the Animal Production and Health Division at FAO (listed in alphabetical order): Artem Metlin, Damina Tago Pacheco, Gian Cosseddu, Guiliano Cecchi, Kaori Sudo, Laetitia Lempereur, Madhur Dhingra, and Satya Parida.
- HealthforAnimals Staff: Alexander Rinkus, Carel du Marchie Sarvaas.

The Value of Animal Health Innovations for Sustainable Livestock Transformation

Contents

Figures

Boxes

Abbreviations

Abbreviation	Definition
AAT	African Trypanosomosis
ADGG	African Dairy Genetic Gains
AMR	Antimicrobial Resistance
AU-IBAR	African Union – Interafrican Bureau for Animal Resources
BVD	Bovine Viral Diarrhoea
CO_2eq	Carbon Dioxide Equivalent
DIMCAT	Disease Intelligence & Modelling for Progressive Control of Animal Trypanosomosis in Africa
ELISA	Enzyme-Linked Immunosorbent Assay
FAO	Food and Agriculture Organization of the United Nations
FFS	Farmers Field Schools
GHG	Greenhouse Gas
GLEAM	Global Livestock Environmental Assessment Model
IAEA	International Atomic Energy Agency
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
PAAT	Programme Against African Trypanosomosis
PCP	Progressive Control Pathway
PI	Persistently Infected
PPR	Peste des Petits Ruminants
PRRS	Porcine Reproductive and Respiratory Syndrome
REDI	Remote Early Disease Identification
RENOFARM	Reduce the Need for Antimicrobials on Farms for Sustainable Agrifood Systems Transformation
SDG	Sustainable Development Goal
WOAH	World Organisation for Animal Health

Foreword

Livestock production systems are a vital source of nutrients, livelihoods, and economic opportunities for millions of people around the world, but they are also facing important challenges. Global population growth has increased demand for animal-sourced food, requiring improved resilience and efficiency in the face of accelerating climate change, water scarcity, biodiversity loss and emerging zoonoses. In this landscape, safeguarding and improving animal health is crucial, as it contributes to protecting public health, improving animal welfare, and reducing the pressure on ecosystems.

The Food and Agriculture Organization of the United Nations (FAO) implements the One Health approach to improve animal health for a more productive and sustainable livestock sector. FAO undertakes a wide range of technical activities from the development of tools and the generation of evidence to the provision of policy support and the development of field-level capacity. Through such initiatives, FAO supports countries in meeting the Sustainable Development Goals and achieving the four betters: Better Production, Better Nutrition, a Better Environment, and a Better Life, leaving no one behind.

This joint FAO–HealthforAnimals publication builds on the FAO report "*Pathways to Lower Emissions: A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems*" published in 2023, which identified key areas of interventions to reduce greenhouse gas emissions from the livestock sector, including animal health. This publication delves deeper into this aspect, presenting real-world examples that demonstrate how innovations in animal health can contribute to climate change adaptation and mitigation while also improving productivity and strengthening the resilience of livestock systems.

As we face the dual challenge of feeding a growing population and protecting our planet's resources, animal health must be recognized as a strategic investment. Animal health innovations, when tailored to each context's challenges, production systems and needs, are more than technical solutions; they are enablers of change as we meet the dual challenges of feeding a growing population and protecting the planet's natural resources.

I am confident that the insights presented in this report will help inform decisions and inspire collaborative action toward a more sustainable and resilient future for livestock production and agrifood systems as a whole.

Thanawat Tiensin
Assistant Director-General,
Director, Animal Production and Health Division (NSA)
and Chief Veterinarian
Food and Agriculture Organization of the United Nations

Introduction

Improving animal health within the global livestock sector is increasingly recognized as a compelling strategy for both reducing greenhouse gas emissions and meeting rising demand for safe, nutritious animal-source foods, while also promoting optimal animal welfare.

Livestock diseases increase both total greenhouse gas emissions and emissions intensity by reducing animal productivity, meaning more animals are needed to produce the same amount of meat, milk, fish and eggs. Sick animals take longer to reach market weight, if they achieve it at all, and require more feed and resources while emitting methane and other gases over an extended period.

These losses undermine not only the environmental sustainability of the livestock sector but also farmers' incomes and can have downstream effects on human food and nutrition security. Additionally, disease-related livestock losses lead to inefficient land and resource use, contributing to deforestation and further emissions from land-use change, as well as the need to use antimicrobials for animal treatment.

Livestock diseases increase total emissions and emissions intensity around the world, including in high-income countries, where sub-clinical diseases can lead to silent losses throughout the value chain. However, the effects of animal disease are particularly acute in developing countries, where veterinary infrastructure is typically more limited. An outbreak of cattle disease affecting 20 per cent of a herd, for example, is linked to a 60 per cent increase in emissions in low-income countries compared to 42 per cent increase in high-income countries.[1] This also has implications for food security and human health within the sphere of One Health.

> *Animal health innovations outlined in this report overlap with other pathways...which represent a combined potential reduction in livestock-related greenhouse gas emissions of 35 per cent.*

In its 2023 publication, *Pathways to Lower Emissions: A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems,*[2] the Food and Agriculture Organization of the United Nations (FAO) identified improved animal health, as well as several related areas, as a key pathway towards reducing emissions from livestock agrifood systems. While this provides a general direction, specific solutions will heavily depend on the local context and specifics of each livestock production system, as there is no one-size-fits-all approach.

This report builds on *Pathways to Lower Emissions* by providing practical examples of context-specific actions that can be taken to support improved animal health, identifying the available and emerging innovations, their emissions reduction potential and opportunities for scaling up adoption.

Many of the animal health innovations outlined in this report overlap with other pathways identified by FAO, including feed and nutrition improvements, breeding, and rumen manipulation, which represent a combined global technical reduction potential in livestock-related greenhouse gas emissions of 35 per cent.

Considering the livestock sector represents 12 per cent of all anthropogenic greenhouse gas emissions, a 35 per cent reduction from animal health innovations and related technologies would equal a reduction in total global emissions of approximately four per cent.

More broadly, addressing livestock health is an essential component of building climate resilience, and achieving the UN's Sustainable Development Goal 2 to end hunger without exceeding the 1.5C threshold of global temperature rises.[3] In many low- and middle-income countries, poor livestock health and inadequate animal nutrition contribute both to increased greenhouse gas emissions intensity and to climate vulnerability. On the other hand, healthier animals can better adapt to climate extremes, which reduces the emissions intensity per unit of meat, milk and eggs while increasing overall productivity. This means a more climate-resilient sector that also generates sustainable livelihoods and food security.

While not an exhaustive review, this report sets out some of the proven categories of animal health interventions, including vaccines, parasite control, biosecurity measures, diagnostics, improved feed and selective breeding for health. Each intervention profile provides an overview, the evidence for emissions reductions, and case studies. The report also outlines the prerequisites for implementation and challenges to scaling up the innovations detailed. Future assessments may expand in scope to include the additional environmental impact of animal health improvements, such as water use, soil health and biodiversity, as well as socio-economic co-benefits.

Both low-tech and cutting-edge solutions exist globally, with more emerging, but fostering the necessary change and widespread adoption requires greater investment, supportive policies, open-mindedness, and strategic partnerships. The transition will require input from all animal health stakeholders, from researchers to policymakers, the private sector, veterinarians, farmers, and consumers. FAO supports this transition under its global plan of action for sustainable livestock transformation,[4] which includes safeguarding animal and public health, and events such as the Global Conference on Sustainable Livestock, while HealthforAnimals champions the contribution of the private sector towards improving the sustainability of livestock through healthier animals.

Relationship between animal health and GHG emissions

Greenhouse gas (GHG) emissions are generated throughout the entire agrifood value chain and can be broadly grouped into three main compartments, based on the processes that generate them: (1) upstream, (2) on-farm, and (3) downstream.

In livestock agrifood systems, upstream emissions are mostly associated with feed production, including emissions from land-use change, cropping activities, and fertilizer use, as well as feed transport and processing.

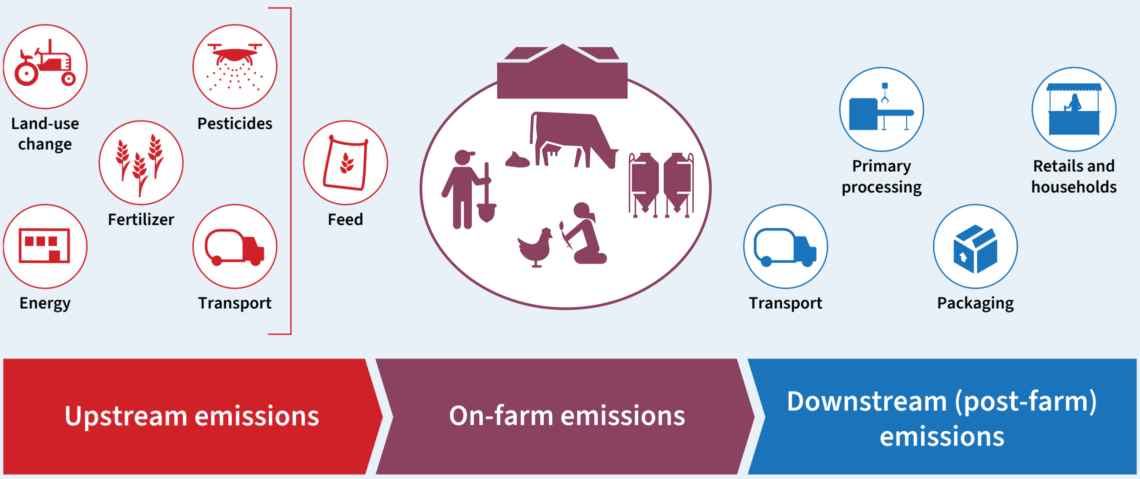
On-farm emissions arise from animal physiological processes such as enteric fermentations, but also from manure management and animal husbandry, housing, and operations such as milking.

Downstream emissions occur after the farm gate and include those from processing, refrigeration, packaging, distribution, retail, consumption, and waste disposal from final consumer.[5]

In some instances, inefficiencies at one state can create a cascading effect across all stages in the value chain, thus contributing to unnecessary GHG emissions and inefficient resource use.

Animal health and welfare are of critical importance along the entire value chain. Impaired health and welfare are associated with higher mortality, reduced growth rates, greater culling, and diminished reproductive and productive performance. These on-farm inefficiencies generate a loop effect by increasing the demand for extra upstream inputs (e.g., feed, water, replacement animals) to maintain the same production level.

Figure 1. Overview of livestock production chain and different sources of emissions and gases[24]



Concurrently, the downstream compartment will be affected by lower production and higher rejection and disposal rates of animal-sourced foods that do not satisfy quality, safety, and regulatory standards.[6] WOAH estimates that animal disease globally leads to around 20 percent losses of terrestrial animal products, which translates into economic losses and potential food security implications.[7] Collectively, these factors can contribute to increased greenhouse gas emissions across the entire production chain.

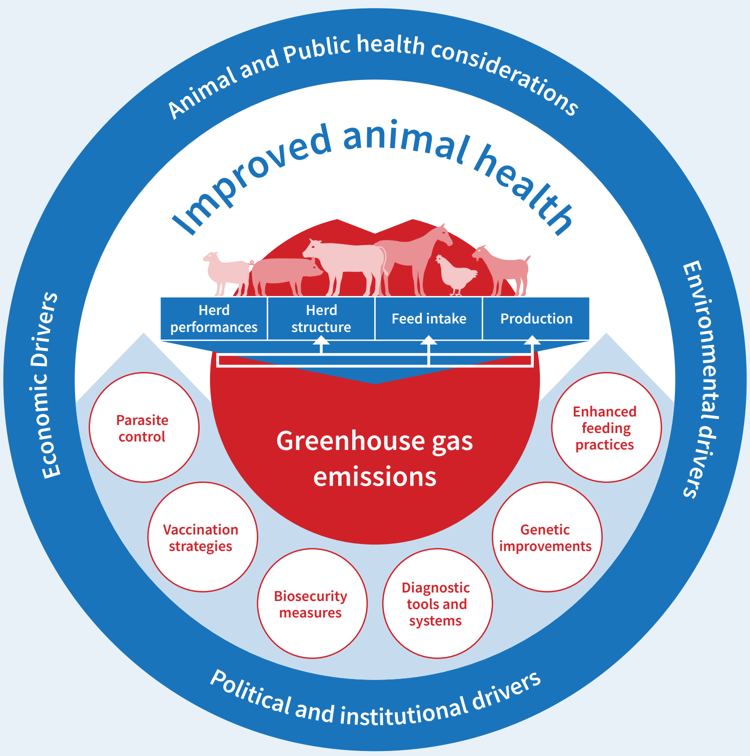
For example, a dairy cattle herd with high mastitis and/or lameness prevalence, will have lower productivity (low output), will require more feed and veterinary care to produce the final output (high inputs), and higher involuntary culling rates due to impaired herd conditions and potential higher milk discards due to contamination (high losses). Ultimately, this means poor livestock health leads to low outputs with high input requirements and high losses, undermining sustainable production.[8,9,10,11,12]

Reducing Emissions through Animal Health Interventions

The implementation of animal health interventions can impact absolute and relative GHG emissions from agrifood systems (Box 1) through several direct and indirect effects (Figure 2) and is often overlooked as an option to reduce environmental impacts from livestock agrifood systems.

The implementation of animal health interventions is typically guided by four key drivers: (1) animal and public health considerations, (2) political and institutional factors; (3) socio-economic aspects and (4) environmental concerns.

Figure 2. Drivers and major effects of animal health interventions influencing greenhouse gas (GHG) emissions



Box 1. Emission intensity and Total emissions

GHG emissions can be expressed in different metrics, each offering different insights. The most frequently used are **total emissions** and **emission intensity** (or carbon footprint).

Total emissions represent the total amount of GHG emitted by the system from all sources, expressed in kg of CO2 equivalent (CO2eq).[13]

Emission intensity represents the GHG emitted in kg of CO2 equivalent to produce the functional unit, which commonly is expressed as unit of product (kg CO2eq/kg meat or milk) or protein (kg CO2 eq/kg protein). This indicator facilitates the assessment of environmental efficiency across different systems or under different conditions. (FAO, 2023).

Animal health interventions are mostly driven by animal and public health considerations, which incorporate the necessity to control, minimize and, as far as possible, eradicate endemic and transboundary diseases, avoid zoonoses spillover, and address antimicrobial resistance.

Moreover, political and institutional factors like the effectiveness of regulatory frameworks and policy commitments also affect the implementation of animal health interventions, together with economic drivers such as market access requirements, cost-effectiveness and production losses prevention.

Environmental drivers, such as climate change are becoming more important in shaping animal health priorities. Improved health can be a tool for achieving climate goals, as outlined in FAO's 2022 report – *The Role of Animal Health in National Climate Commitments*. Furthermore, a changing climate can influence animal health, for example through changes in the spread and distribution of diseases resulting from shifts in pathogen ecology and vectors dynamics.[14,15,16,17]

The magnitude of how interventions can reduce GHG emission intensity varies according to the type of disease or syndrome tackled, the interventions implemented, context and the livestock production systems considered. For instance:

- **Mastitis prevention could result in a 6 percent reduction in emissions intensity** for clinical cases and around 4 percent for subclinical ones, according to evidence from Northern European dairy cattle systems.[18,19]
- **Targeting bovine trypanosomosis could reduce emissions intensity by up to 8 percent** in East Africa.[20]
- **Control of endoparasites infections can potentially reduce GHG emission intensity by up to 13 percent** in Scottish meat sheep systems.[21]
- **Preventing Porcine Reproductive and Respiratory syndrome could lead to emission intensity reductions ranging from 5 to 43 percent** in monogastric species.[22]
- **Mitigating Highly Pathogenic Avian Influenza was associated with up to 38 percent emissions intensity reduction** in global poultry systems.[23]

When production is maintained with fewer animals or lower inputs, animal health improvements can effectively deliver "avoided emissions", lowering emissions compared to scenarios without better health and welfare.

At the same time, knock-on effects. must be carefully evaluated. For example, productivity gains could encourage herd expansion or they could lower production costs and prices, increasing the demand for livestock products. These rebound effects may offset some of the emissions savings.

Generating robust evidence on these dynamics is crucial to capture the full co-benefit of improving animal health for more sustainable and resilient livestock systems (Box 2). While no universal solution exists, context-specific strategies that consider local health priorities, economic, environmental, and political aspects should be applied. Understanding and quantifying the short- and long-term links between animal health and GHG emissions remains challenging, particularly due to data limitations.

Standardized tools are essential to understand the impact of different health interventions at different scales and to transform livestock systems into more sustainable and resilient with healthier animals and reduced environmental pressure.

Box 2. Methodologies to assess GHG emissions in livestock

The Intergovernmental Panel on Climate Change (IPCC) has proposed a tiered approach for estimating GHG emissions from livestock agrifood systems, depending on data availability, technical capacity and the desired level of accuracy.[25,26]

The Tier 1 approach uses default emission factors applied to general livestock categories and regional averages which are multiplied by the livestock population size. While this approach is useful for countries with limited data, it cannot account for changes in management practices or the benefits of interventions such as improved animal health.

The Tier 2 approach (or the more advanced Tier 3) allows for a more detailed and accurate estimate of GHG by incorporating national or sub-national livestock production system and cohort-specific activity data (e.g., live weights, diet composition, manure management…). As a result, these Tiers allow the quantification of emission reductions resulting from health improvements.

A key tool supporting Tier 2 GHG assessments is the **Global Livestock Environmental Assessment Model (GLEAM)**, developed by the FAO. GLEAM is a modeling framework that simulates the interactions between livestock production activities and the environment. The model can operate at (sub) national, regional, and global scales, and is designed to analyze multiple environmental dimensions of livestock systems and calculate environmental impacts of livestock supply chains under different scenarios and for different interventions.

Interventions

1. Vaccines

Overview

- **Vaccines are proven, cost-effective tools for disease control and reducing AMR risk,** reducing greenhouse gas emissions by preventing diseases that undermine productivity and cause unnecessary losses, which also protects producer livelihoods.
- **Disease prevention through vaccination also enables a reduction in land** required for production, an important step towards minimizing emissions from land-use changes.
- **New vaccine innovations will provide greater opportunities** not just for disease control, but also the possibility of reducing the methane generated by livestock with vaccines that target enteric fermentation.

Vaccines are the most effective tool for preventing animal diseases and exist in a number of forms for many of the most common diseases affecting livestock. In recent years, advances in vaccinology have overcome several challenges holding back disease control, from heat-stable vaccines that do not require a cold chain to custom vaccines and precision delivery systems that can vaccinate animals in a more efficient, cost-effective manner.

Controlling key endemic diseases for which vaccines exist has been found to reduce emissions intensity per unit of meat and milk by improving productivity per animal and reducing unnecessary losses. Preventing disease through vaccination also reduces the need for treatment including the use of antimicrobials, which in turn supports the goals of FAO's Reduce the Need for Antimicrobials on Farms for Sustainable Agrifood Systems Transformation (RENOFARM) initiative (See *'Implementation: Challenges and Solutions'* section for more information on the RENOFARM project and how it can be a model for helping scale up interventions).

For example, vaccinating cattle against the tick-borne East Coast Fever has been estimated to increase productivity by as much as 27 per cent and lead to a reduction of emissions intensity by up to 40 per cent.[27] Meanwhile, controlling porcine reproductive and respiratory syndrome (PRRS) in commercial swine operations has been modeled to bring down emissions intensity by 22.5 per cent per kilogram of meat.[28]

Vaccination has also been linked to land use, which accounts for 19 per cent of global agrifood systems emissions.[29] Globally, a 40 per cent vaccination rate for cattle in a given year is associated with a 5.2 per cent reduction in land required for livestock production because the same output can be achieved with fewer animals.[30] This increases to a 12.8 per cent reduction in land required for livestock in countries like Brazil where animal agriculture is a significant sector.[31]

A vaccine that specifically targets the reduction of methane emissions in livestock is also a growing area of research and development. Research projects are exploring if and how vaccine technologies could be used to deliver antibodies that inhibit methane-producing microbes.[32] Such a product would offer an efficient mechanism for reducing direct methane emissions compared to existing solutions, such as feed additives, which must be present in each mouthful of feed to be effective.

Box 3. Emissions Intensity Reductions through Prevention

An increasing number of studies have assessed the emissions impact of preventing common livestock diseases. These analyses consistently show that effective disease control, especially through vaccination, can significantly improve productivity and reduce emissions intensity across different species and production systems. The examples below illustrate the scale of these benefits at both national and global levels.

Impact of vaccination against East Coast Fever[33]

Country	Productivity gain	Emissions intensity reduction
Kenya	25%	14–19%
Uganda	4–27%	8–40%
Tanzania	12–23%	20–29%

Reductions in emissions intensity through disease control in various livestock systems[34]

Disease	Livestock system	Emissions intensity reduction
Foot and mouth disease	Intensive dairy	7.88%
	Extensive beef	9.11%
PRRS	Commercial swine	22.5%
Classical swine fever	Commercial swine	12.5%
Low pathogenicity avian influenza	Backyard poultry	1.89%
Avian bronchitis	Backyard poultry	11.3%

CASE STUDY

Sparing swine from PRRS through vaccination

Primary species affected: Swine

Disease severity: Up to 100% mortality in highly pathogenic strains[35]

Regions affected: Global

Prevalence: Highly endemic. ~35% prevalence in major producers like US and China.[36,37]

CHALLENGE

Porcine Reproductive and Respiratory Syndrome (PRRS) is one of the most widespread and economically damaging diseases in the global swine sector. Transmitted through close contact and contaminated bodily fluids, it impairs reproduction in sows and causes respiratory issues in piglets, causing up to 35 per cent more stillbirths and reducing daily weight gain by 85 per cent.[38] In the United States alone, PRRS was responsible for an estimated $1.2 billion in losses between 2016 and 2020, driven by increased mortality, reduced growth rates, and higher input costs.[39] Each outbreak not only impacts productivity but also increases emissions, as more animals are needed to achieve the same output.

INTERVENTION

Vaccination is a central strategy for PRRS control. While vaccination adoption varies across regions, consistent use has shown measurable benefits. Research is underway to expand the availability of vaccines to new routes of administration such as an oral vaccine. This type of work could further improve uptake, making widespread, consistent immunization more achievable, especially in lower-resource settings.

OUTCOME

- **Animal Health Impact**: In herds where vaccination is applied continuously rather than intermittently, nursery piglet mortality has been reduced by up to 50 per cent.[40]
- **Reproductive & Productive Performance**: Effective PRRS vaccination results in a reduction in stillbirths and improves weight gain within the herd.[41,42]
- **GHG Emissions Impact**: Modeling shows that controlling PRRS can lower emissions intensity by 22.5% per kilogram of pork produced.[43]
- **One Health Benefit:** PRRS control may reduce the need for antibiotics by lowering the incidence of secondary infections, which can contribute to efforts to address AMR.

CASE STUDY

Vaccination to achieve PPR eradication

Primary species affected: Sheep, goats

Disease severity: Morbidity and mortality rates as high as 80–100% in unexposed populations[44]

Regions affected: Asia, Africa, Middle East

Prevalence: Approximately 40% across Africa and Asia[45]

CHALLENGE

Peste des petits ruminants (PPR) is a highly contagious viral disease of sheep and goats in countries in Asia, the Middle East and Africa; It has also been recently reported in Europe. Millions of rural households in low- and middle-income countries in these continents depend on small ruminants for income and food security. PPR can cause mortality rates up to 90%, with global economic losses estimated at $1.7 billion annually.[46] Smallholder and pastoralist communities bear most of these losses, especially where veterinary services and cold-chain vaccines cannot easily reach remote herders. Without effective control, outbreaks drive higher emissions as more animals and inputs are needed to maintain output, which has broad implications since small ruminants make up a significant proportion of global livestock populations.

INTERVENTION

In 2015, the international community including FAO and WOAH set a target to eradicate PPR by 2030, using lessons from rinderpest eradication to scale up vaccination, surveillance, and veterinary outreach. Hundreds of millions of vaccine doses have already been administered, reducing outbreaks — but reaching remote areas without cold chains remains difficult. A partnership between the International Livestock Research Institute (ILRI), Mali's Central Veterinary Laboratory, and the Technologies for African Agricultural Transformation Livestock program is tackling the thermolabile nature of PPR vaccine, replacing it with a thermotolerant vaccine. This innovation aims to help Mali immunize one million sheep and goats across 35,000 households without relying on a continuous cold chain.

OUTCOME

- **Animal Health Impact:** Between 2015 and 2018, more than 333 million doses of PPR vaccine were administered across 12 countries, contributing to a 66 per cent reduction in outbreaks globally by 2019, from 3,688 to 1,218.[47]

- **Reproductive & Productive Performance:** While direct animal-level productivity data are limited, studies consistently show that vaccination improves farm income and meat availability, indicating that preventing PPR leads to meaningful gains in herd productivity.[48,49,50]

- **GHG Emissions Impact:** While PPR is not typically modeled for emissions, studies of small ruminant health show clear links between improved survival and lower environmental impact.[51,52]

- **One Health Impact:** PPR is most prevalent in developing regions where protecting small ruminant health can directly contribute to food security for vulnerable communities, which may help contribute to improved human nutrition.

2. Parasite control

Overview

- **Disease-carrying parasites significantly harm livestock health**, affecting appetite, digestion, and weight gain, leading to suffering and possibly death if left untreated.
- **Infected animals convert feed into energy less efficiently**, leading to slower growth rates and lower milk or meat yields. This means more animals, feed, and time are required to produce the same amount of food, increasing emissions intensity.
- **Parasites can also weaken immune systems**, making animals more susceptible to secondary infections that further reduce productivity and may require antimicrobial use for treatment.
- **Controlling parasites not only prevents these losses but also reduces emissions intensity** by improving feed conversion efficiency, overall herd health and manure composition.

Disease-carrying parasites come in a number of forms and fall into two categories: endoparasites or internal parasites, such as worms; and ectoparasites, which are found externally on the skin or in the coat of an animal, such as mites and ticks. Parasites are a widespread and significant cause of livestock ill-health and losses globally.

Ticks and tick-borne diseases, for example, affect an estimated 80 per cent of cattle worldwide[53] while the prevalence of parasitic worms in poultry can be as high as 84.8 per cent.[54] Climate change, trade and increased global movement are all contributing to the spread of ticks, worms and other vectors, which can cause conditions that impact vital organs, reduce appetite and cause lameness, all of which harms the health and development of livestock.

Parasitic disease results in both productivity losses and heightened emissions intensity, as well as increased risk to people, whose health is connected to animals via the interconnected concept of One Health. In many cases, the subclinical manifestation of parasitic diseases cause 'silent losses' where animals show no outward symptoms, yet their health and productivity are compromised.

Parasite control offers significant reductions in both ill-health and emissions intensity, particularly in emerging markets and rural areas where parasites can be more widespread. Preventative products include injections, topical treatments and oral parasiticides, with vaccines and "green" parasiticides that are absorbed before entering the environment on the horizon to increase the options for parasite control. Strategies for parasite control include knowledge sharing, capacity building and the promotion of best practices. For example, FAO contributes to this by developing comprehensive guidelines and providing training and platforms for information exchange.[55] To ensure these benefits are sustained over time, parasite control strategies must prioritize responsible use of treatments to help avoid anthelmintic resistance. Surveillance and biosecurity can play a key role in supporting this goal by enabling early detection and limiting parasite spread.

CASE STUDY

Strategies for addressing endoparasites and associated emissions

Primary species affected: All

Disease severity: Widespread chronic morbidity; can cause death in heavily infested or untreated animals.

Regions affected: Global

Prevalence: Endemic across nearly all production systems. E.g. as high as ~80% in cattle and poultry.[56,57]

CHALLENGE

Endoparasites are a common health challenge for livestock around the world. Cysts, eggs and larvae can be ingested through contaminated food, water or pasture, after which they impact the internal organs and biological processes of host animals. Endoparasites have been found to increase methane emissions by reducing feed efficiency and productivity. For instance, research has found parasites can increase emissions intensity by 33% in lambs, while another model found every 1% increase in gastrointestinal worm prevalence in ruminants increased absolute emissions by 0.52.%[58,59]

INTERVENTION

Preventative measures, including strategic deworming, can protect livestock against endoparasites and the diseases they carry. Responsible anthelmintic use, guided by diagnostics, local risk factors, and epidemiology, can help reduce parasite burdens while preserving treatment effectiveness and limiting resistance. Complementary practices such as pasture management can also lower parasite exposure and support sustainable control.

OUTCOME

- **Animal Health Impact:** Routine deworming reduces parasite prevalence, improves feed conversion, and prevents clinical signs such as anemia, diarrhea, and weight loss—supporting overall herd health and resilience.
- **Reproductive & Productive Performance:** Controlling endoparasites consistently improves livestock productivity. For example, deworming in Kenya led to productivity gains of up to 27%, while a global meta-analysis on liver fluke found that infection reduces daily weight gain by 9%, which are losses that can be avoided through effective parasite control [60,61]
- **GHG Emissions Impact:** Endoparasite control can reduce emissions intensity by up to 20%, as shown in Kenyan livestock systems.[62] Separately, a global study in lambs found that animals treated only after clinical signs appeared had 10% higher emissions per kilogram of weight gain compared to those given strategically timed prophylactic treatment based on parasite lifecycles.[63]
- **One Health Impact:** Control of zoonotic endoparasites such as *Fasciloa hepatica* and *Echinococcus granulosus* in livestock animals can help avoid these parasites and associated parasitic infections from spillover to human populations.

CASE STUDY

Progressive control of animal trypanosomosis in Africa

Primary species affected: Cattle, sheep, goats, horses and pigs

Regions affected: Sub-Saharan Africa

Disease severity: Up to 50-100% mortality in fully susceptible, untreated ruminant populations[64]

Prevalence: 12% across Africa, but as high as 51% in individual countries[65]

CHALLENGE

African animal trypanosomosis (AAT) is a parasitic, tsetse-transmitted disease affecting cattle and other livestock across at least 37 African countries.[66] It decreases yields, reduces fertility, and can cause widespread mortality especially in naive populations, resulting in economic losses exceeding $4.5 billion annually. The burden is especially severe in low-resource areas, where veterinary services, diagnostics, and treatments are limited. Beyond direct productivity losses, AAT raises emissions intensity per unit of milk or meat and restricts access to fertile grazing lands, which undermines food security, rural incomes, and sustainability.[67]

INTERVENTION

To address these impacts, the Programme Against African Trypanosomosis (PAAT), established by FAO, WHO, IAEA, and AU-IBAR, supports affected countries in developing coordinated evidence-based control strategies. In 2024, FAO launched "Disease intelligence & modeling for progressive control of animal trypanosomosis in Africa (DIMCAT)" to enhance in-country surveillance (i.e. the 'atlas' initiative) and predict trends across diverse geographies and time scales.[68] By generating accurate risk maps and analyzing climate data, improved AAT intelligence allows for better-targeted interventions under a Progressive Control Pathway (PCP).[69] Together, the PCP and atlases offer a scalable blueprint that can be tailored to national and regional contexts. Alongside other innovations, such as the development of safer trypanocides with novel modes of action to address resistance, this approach can help reduce the impact of AAT while safeguarding productivity, rural livelihoods and the environment.[70]

OUTCOME

- **Animal Health Impact**: Control of AAT can reduce prevalence, from 30% to 5%, which will ultimately reduce morbidity and mortality across a herd.[71]
- **Reproductive & Productive Performance**: AAT reduces milk production by 10–40% and cattle offtake by 5–30%, meaning control can produce increased milk yield, better growth rates, and improved reproductive performance.[72]
- **GHG Emissions Impact**: Eliminating AAT in East Africa is estimated to reduce emissions intensity by up to eight per cent, due to improved fertility, higher milk yields, and better animal condition.[73]
- **One Health Impact:** Controlling trypanosomosis in animals reduces vector density and disease risk in humans, notably from Trypanosoma brucei rhodesiense, which causes human African trypanosomiasis (sleeping sickness).

3. Biosecurity

Overview

- **Biosecurity plays a vital role in disease prevention and emissions reduction by** reducing the risk of pathogens infecting or spreading among livestock populations.
- **Biosecurity measures can be implemented on farms of all size and sophistication** through "low-tech" strategies like simple sanitation practices, such as boot wash stations, to more "high-tech" solutions like advanced ventilation systems. Participatory approaches such as FAO's Progressive Management Pathway for Terrestrial Animal Biosecurity (FAO-PMP-TAB) can support the design of contextualized solutions to promote biosecurity.
- **Biosecurity measures work in tandem with monitoring and surveillance** to allow for early detection of disease outbreaks, minimizing potential losses.

Biosecurity is a set of measures used to prevent the introduction and spread of diseases in animals and reduce the risk of spillover infections in people. This includes preventing introduction, containing spread, assessing and managing risks. On-farm measures range from simple procedures such as boot washing by farmers or the isolation of sick animals to waste management and advanced air filtration systems to clean the air breathed by animals kept indoors. Biosecurity measures such as quarantine periods can also be implemented at borders to stop disease spread between countries. By preventing the spread of disease, biosecurity plays a vital role in protecting animal health.

Biosecurity is important not only to prevent external sources of disease but to avert further spread within a population by preventing sick animals from mixing and infecting the rest of the farm or herd. Cattle mixing with other herds in Bhutan, for example, were found to be more than five times more likely to have had foot and mouth disease than those that did not, with foot and mouth disease more than 14 times more likely among cattle fed kitchen waste by farmers.[74]

Implementing physical measures and practices to prevent the spread of disease is particularly important when other control methods are not feasible, such as African Swine Fever, a fatal disease in swine with no vaccine available or Avian Influenza where vaccination may not be permitted. Controlling high pathogenicity avian influenza in high prevalence areas through biosecurity measures and other interventions could reduce emissions intensity by almost 16 per cent.[75]

Highly advanced biosecurity measures – sometimes called "next-generation" biosecurity – apply a layered approach that protects against direct routes of transmission, such as infected breeding stock, combined with protection against indirect transmission through contaminated transport and airborne routes. While this can require sophisticated measures such as air filtration and feed mitigants in diets, one study found this to be highly effective in controlling porcine reproductive and respiratory syndrome (PRRS). In herds using all components of "next-generation" biosecurity, incidence risk fell to 8.9 per cent, compared to 40 per cent for those that did not.[76] Research suggests that preventing PRRS would avoid more than 420,000 tonnes of CO2 equivalent for every 100,000 sows.[77]

CASE STUDY

Biosecurity measures to prevent bovine viral diarrhea (BVD)

Primary species affected: Cattle

Disease severity: Mortality can exceed 50% in calves.[78]

Regions affected: Global

Prevalence: Global seroprevalence estimated at ~42%[79]

CHALLENGE

Bovine viral diarrhea (BVD) is one of the most economically significant and contagious cattle diseases, reducing productivity through abortions, infertility and culling. BVD results in higher veterinary costs and increased calf losses, which directly impacts farm profitability.

This leads to increased feed and resource use per kilogram of beef produced, higher methane emissions due to poor growth rates and greater antibiotic use to treat secondary infections. BVD has been found to drive up beef cattle emissions intensity by as much as 113 per cent.[80]

INTERVENTION

Biosecurity measures are often a critical complement to vaccination. For instance, the recommended control strategy is typically a combination of biosecurity controls and targeted vaccination.

For instance, a combination of vaccination, early diagnostics and biosecurity measures has helped several European countries significantly reduce the prevalence of BVD. Germany's nationwide BVD eradication program reduced persistently infected cattle from 23,792 in 2011 to just 1,005 in 2016 – a 95% decrease.[81]

OUTCOME

- **Animal Health Impact:** Control programs targeting BVD significantly reduce infection rates, reproductive losses, and calf mortality. In persistently infected (PI) animals, mortality can reach 50% within the first year, and intervention can significant reduce these losses.[82]
- **Reproductive & Productive Performance:** BVD control improves fertility, reduces abortions, and increases calf survival, translating to higher herd productivity. Countries with active eradication programs have reported dramatic reductions in PI prevalence and related productivity losses**.**
- **GHG Emissions Impact:** Modeling suggests that controlling BVD in the worst 10 per cent of herds can reduce emissions intensity by up to 12% across emerging and developed markets.[83]
- **One Health Impact:** BVD control may help avoid secondary bacterial infections, which would help reduce the need for antimicrobials. This can help support efforts to address AMR.

CASE STUDY

Reducing mastitis infections through biosecurity

Primary species affected: Cattle, goats, sheep and pigs

Disease severity: Approximately 21% mortality rate for clinical mastitis.[84]

Regions affected: Global, especially sub-Saharan Africa

Prevalence: ~57% prevalence rate. 42% for subclinical mastitis and 15% for clinical[85]

CHALLENGE

Mastitis in livestock, particularly in dairy animals like cows, sheep, and goats, is primarily caused by bacterial infection entering the udder through the teat canal. Contributing factors to the disease include poor milking hygiene, teat injuries, and stress, leading to the inflammation of the mammary gland.

It is one of the most prevalent health challenges for dairy animals. A global metanalysis of prevalence data found that approximately 42% of dairy cattle are affected by subclinical mastitis and 15% by clinical mastitis in global prevalence studies across several decades.[86] Mastitis reduces milk yield and quality and can lead to udder damage and systemic illnesses.

Subclinical mastitis, which lacks visible symptoms, is particularly widespread and is a leading cause of global dairy losses, which has a considerable impact on dairy farm productivity. In particular, the disease affects dairy systems in developing countries, which lack adequate veterinary services. The condition reduces income, increases antimicrobial use, and elevates emissions intensity by decreasing milk yield.

INTERVENTION

Effective biosecurity — even low-cost measures — can break the cycle of reduced income, increased microbial use, and elevated emissions intensity. Practical interventions include:

- Proper cleaning and disinfection of milking equipment
- Post-milking teat dipping
- Separation of infected animals
- Improved barn hygiene and bedding
- Stress reduction and temperature control

In more advanced systems, automated milking technologies now monitor milk conductivity, flow, and color to detect early signs of infection, enabling prompt treatment or isolation before full disease develops.

OUTCOME

- **Animal Health Impact:** Biosecurity interventions reduce infection rates, prevent udder damage, and lower the risk of secondary illness, improving overall health and welfare.
- **Reproductive & Productive Performance:** Mastitis control has been shown to increase milk productivity by up to 14% in Bangladesh, while globally, each case avoided saves approximately $444 in lost yield, treatment, and culling costs.[87] Eliminating the disease could save the global dairy industry more than $23 billion each year.[88]
- **GHG Emissions Impact:** Studies have consistently found positive effects on GHG emissions through mastitis control. For instance, reducing emissions intensity up to 12% in Bangladesh.[89] Another modeling study found improved mastitis management practices reduced emissions intensity by up to 14%.[90]
- **One Health Impact:** Improved udder health reduces the need for antimicrobial treatment, contributing to efforts to address AMR. Better milk quality can also strengthens food safety for people.

Credit: © FAO/Mattia Romano

4. Diagnostics & digital tools

Overview

- **Diagnostics are a critical component of improved animal health**, enabling early detection and containment of livestock diseases before they spread.
- **By identifying infections quickly, farmers and veterinarians can implement targeted interventions** such as quarantine, vaccination, or treatment, reducing the risk of the outbreak spreading.
- **Diagnostics and digital tools enable a reduction in disease-related productivity losses**, meaning fewer animals are needed to produce the same amount of food, lowering emissions intensity and improving the overall sustainability of livestock production.

Diagnostics rely on technologies such as molecular and immuno-assays, blood chemistry, and haematology to detect genome fragments, antigens, proteins, antibodies, or other signs of infection. Detecting diseases as early as possible through diagnostics helps reduce the duration and intensity of treatment, which in turn reduces the emissions burden. Subclinical ketosis, a metabolic disorder in dairy cows diagnosed through blood tests, increases emissions intensity by 2.3%, which early detection can help avoid.[91]

Diagnostic technologies have advanced to allow physical specimens to be tested in a non-laboratory setting, or at the point of care, using portable microfluidic devices, or tiny chips. Point-of-care testing is particularly significant for low- and middle-income countries where livestock disease is more impactful and access to traditional diagnostic laboratories is more limited.

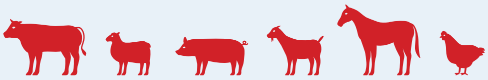
In addition to traditional diagnostic technologies, new digital tools allow for further improvements to health monitoring, enabling diseases to be diagnosed – and treated – sooner, or even predicted based on data analysis and biomarkers.

For example, traditional visual assessments of bovine respiratory disease have a sensitivity of 64.5 per cent and specificity of 69.1 per cent.[92] Remote Early Disease Identification (REDI) systems, powered by artificial intelligence, can improve these metrics to 81.3 and 92.9 per cent, respectively.[93] Remote systems can also monitor behavioral changes, such as reduced activity, socialization and feeding, and have been shown to diagnose potential illness 0.75 days earlier than even trained human observers.[94] Elsewhere, sound monitoring systems have been able to detect the first signs of an individual cough among a herd of animals that would otherwise be missed by the human ear.

These digital systems serve as valuable complements to traditional diagnostic methods, enhancing the accuracy of disease detection and reducing the burden on farm staff by automating routing health monitoring tasks. This early detection enables prompt isolation and treatment before an outbreak affects the entire group, protecting herd health, raising productivity, and reducing emissions intensity.

CASE STUDY

Rapid testing to enable outbreak control



Primary species affected: All

Disease severity: Fast moving outbreaks can lead to entire herd loss

Regions affected: Global

Prevalence: Highly virulent outbreaks can affect entire animal populations

CHALLENGE

Timely and accurate diagnosis is critical in controlling infectious diseases in livestock. However, some traditional diagnostic methods may require seven to 10 days to obtain the results. In the meantime, infections can spread throughout herds or flocks, causing production losses, increased mortality, and higher emissions intensity due to extended disease duration, inefficient feed conversion, and the need to incinerate/dispose the carcasses in a safe manner. Without rapid testing, farmers may rely on clinical signs to identify illness, which can be non-specific or appear too late for effective intervention.

INTERVENTION

Advances in diagnostics are enabling faster, more accurate disease detection. For instance, enzyme-linked immunosorbent assays (ELISA) can provide pen-side results that enable immediate action. A similar technology, lateral flow assays can also offer a highly portable alternative for near-immediate results. In field trials across Pakistan, Ethiopia, Côte d'Ivoire, and Uganda, lateral flow assays for peste des petits ruminants (PPR) showed 84% sensitivity and 95% specificity compared to PCR — a high accuracy rate for field-deployable tools.[95]

OUTCOME

- **Animal Health Impact:** Rapid diagnostics enable early detection and containment of fast-moving diseases, significantly reducing severity and mortality. By shortening the time from infection to intervention, rapid testing helps protect animal welfare and prevent unnecessary loss.

- **Reproductive & Productive Performance:** Earlier intervention limits production losses by preserving feed efficiency, fertility, and growth rates. One US study on anaplasmosis in cattle found the cost of a clinical case to be $660 per head, compared to just $7 for a diagnostic test, and $18–22 with follow-up treatment.[96]

- **GHG Emissions Impact:** While no studies directly quantify the GHG impact of early disease detection, reducing outbreak prevalence clearly lowers emissions. For fast-spreading, high-impact diseases like Bovine Viral Diarrhea, which can increase emissions intensity in beef cattle by up to 130%, early detection is essential to prevent widespread infection and reduce emissions intensity across the herd.[97]

- **One Health Impact:** Rapid diagnostics can help limit the spread of potentially zoonotic diseases by enabling early containment.

CASE STUDY

Digital tracking to support early diagnosis and welfare for cattle

Primary species affected: Cattle

Regions affected: Global

CHALLENGE

Diseases often begin in cattle with subtle changes in their behavioral patterns. For example, pre-weaned calves with pneumonia will increase lying time and reduce movement, while adult cows with lameness or mastitis will show altered step activity. These diseases are widespread and highly contagious, transmitted via inhalation, contact, or through the teat canal in adults. For example, a recent study found up to a third of UK pre-weaned calves experience respiratory illnesses, which can lead to lung damage and correlate with reduced growth and performance.[98] Separating these animals from the herd as early as possible after they have contracted a disease is therefore very important, and so too is identifying the disease as early as possible.

INTERVENTION

Farmers often rely on visual or auditory cues—like limping or coughing—to detect illness, but these signs can appear late and be unreliable. Digital tools now offer earlier, more accurate detection by continuously monitoring behavior and physiology. For example, accelerometer-based pedometers attached to a cow's leg or collar can monitor step activity and lying behavior, enabling early detection of lameness or symptoms like lethargy. Likewise, an AI sound-monitoring platform detects respiratory disease in pigs earlier than clinical observation with studies finding its alerts aligned with lab-confirmed infections.[99] These systems enable quicker intervention, reduce disease spread, and support better outcomes for health, productivity, and emissions.

OUTCOME

- **Animal Health Impact:** Earlier detection enables earlier treatment and improved welfare. For example, a less than five per cent drop in a cow's daily step count can identify lameness up to 10 days before clinical signs according to one study.[100] Another found that audio monitoring successfully acted as an 'early warning system' for illness.[101]

- **Reproductive & Productive Performance:** Early detection prevents lasting damage in calves and adults, particularly for diseases that impact growth and long-term productivity. Detecting illness early protects daily weight gain and overall performance potential, helping ensure optimal returns throughout the animal's life cycle.

- **Emissions Impact:** Little research exists on the impact of digital tools on GHG emissions. However, identifying subclinical disease means animals can be treated or removed from the herd earlier, which aligns with existing research on reductions in emissions intensity.

- **One Health Impact:** Digital health monitoring can help support zoonotic disease surveillance, helping avoid spillover into people.

5. Improved feed

Overview

- **Proper nutrition is essential for livestock health, productivity and sustainability**, ensuring animals efficiently convert feed into meat and milk.
- **Feed additives can offer an additional tool to complement balanced diets** to address emissions by reducing methane production in the digestive system.
- **Other supplements can also modify gut fermentation to lower methane output**, including probiotics, tannins, essential oils, and certain fats.
- **These additives enhance feed efficiency, reduce waste, and help make livestock production more climate-friendly** when combined with high-quality nutrition.

Proper livestock nutrition plays an essential role in healthy growth and development, but it is also an emissions reduction strategy. Methane is emitted during the digestive process known as enteric fermentation, while inadequate nutrition can limit growth and increase susceptibility to illness. Optimizing cattle nutrition helps animals grow more efficiently, making them less susceptible to disease and infection, which ultimately increases productivity and reduces both total emissions and emissions intensity.

Undernourished cattle have been found to emit up to seven per cent more methane per unit of food due to their poor health, while methane wastage increases 11 per cent in underfed cattle.[102] Undernutrition is most common in low- and middle-income countries where access to adequate quality feed is more likely to be limited. In contrast, healthy, balanced feeding can increase milk yields while also reducing land use change through improved feed crop yields.

Feed additives and nutritional supplements can be used to enhance nutrient uptake and digestive efficiency in livestock. By optimizing the bioavailability of essential nutrients such as amino acids, vitamins and minerals, these additives support the conversion of feed into energy, protein, and other growth-supporting compounds. This supports healthier, disease-free growth that enables animals to reach market weight more efficiently, which reduces the total feed and other resources required per unit of output.

Enhanced digestibility of feed, meanwhile, contributes to improved immune function, lower disease incidence and improved reproductive performance in livestock. These three core animal health indicators in turn correspond to lower mortality and morbidity rates, reducing the environmental and economic burden of disease management.

Improvements in feed digestibility of just 10 per cent have been shown to correspond to a reduction of up to 20 per cent from livestock enteric methane emissions, due to a more efficient fermentation process in the rumen, where less energy is lost as methane and more is captured as nutrients.[103]

Additionally, emerging feed additives can also manipulate the gut microbiome to reduce methane production in the rumen. Additives like red seaweed and 3-NOP (3-nitrooxypropanol), for example, inhibit the enzymes that produce methane in cattle rumen, cutting emissions without affecting digestion. Studies indicate 3-NOP can reduce methane production by as much as 32.7 per cent.[104] Other additives reduce methane emissions by increasing the production of propionate, a more efficient source of energy, reducing the energy lost as methane and increasing the energy converted by livestock. This also results in less manure, which also means lower levels of greenhouse gas emissions.

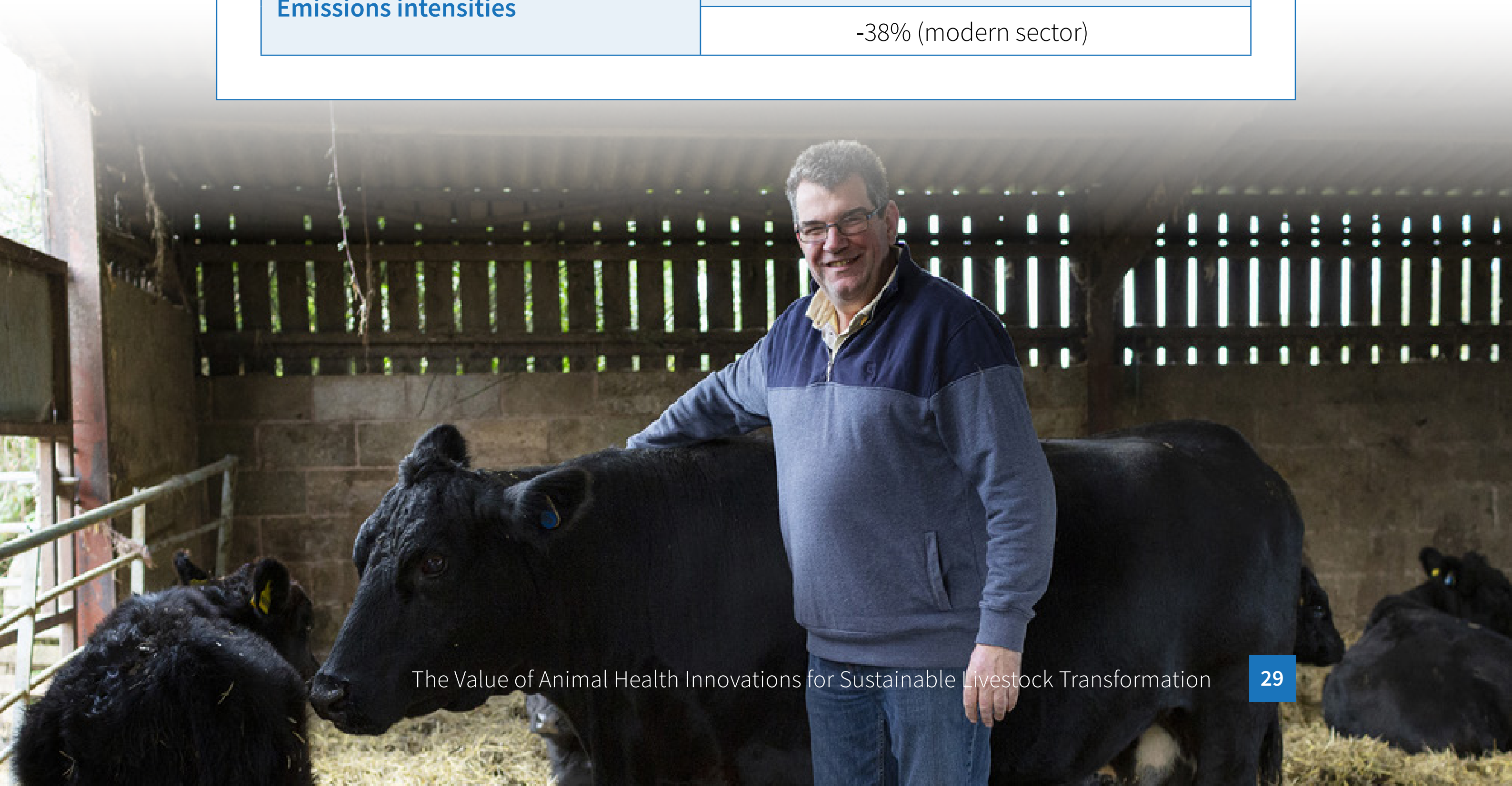
Box 4. Impact of feed and nutrition improvements in the dairy sector

FAO's Pathways towards Lower Emissions report finds that 'feed and nutrition improvements' have the potential to reduce global livestock emissions intensity by approximately 12% by 2050. This intervention includes providing higher-quality feeds (e.g. replacing low-quality hay with more nutritious options), adding supplements to feed, etc. Against this backdrop, field-level studies help bring these projections to life. For example, a life-cycle assessment conducted in Tanzania's southern highlands reveals that enhancements in feeding, through both management practices and crop yield improvements, can boost milk yields, while cutting emissions intensity. This dual benefit of reduced greenhouse gas emissions intensity and increased productivity underscores the promise of strategic nutrition interventions in the dairy sector.

Impact of improved feeding in Tanzanian dairy sector[125]

A recent study conducted life cycle assessment and simulation modeling to evaluate how improved feeding practices would affect yields and emissions across 'Traditional' systems with local cattle breeds and 'Modern' systems that used improved genetics in Tanzania.

Milk yields	+60.1%
Emissions intensities	-52.4% (traditional sector)
	-38% (modern sector)



CASE STUDY

Optimizing livestock performance, health and emissions with feed additives

Primary species affected: All

Regions affected: Global

CHALLENGE

Maintaining optimal animal health is critical not only for productivity but also for sustainable livestock production. Poor gut health in livestock leads to inefficient digestion and susceptibility to disease, both of which ultimately lead to higher greenhouse gas emissions. Additives that can improve the gut microbiome within a livestock animal can ensure better uptake of nutrients to promote a hardier immune system, while improving feed efficiency and animal growth. This means fewer emissions and better outcomes for the farmer.

INTERVENTION

A recent global meta-analysis assessed the impact of non-antibiotic feed additives — including probiotics, prebiotics, organic acids, phytogenics, and enzymes — on livestock health and performance.[105] These additives work by improving gut microbiota balance, strengthening immune function, and enhancing nutrient absorption, all without relying on antibiotics. This means a strong natural immune system for the animal that can process feed more efficiently, which means higher growth rate and lower emissions intensity.

OUTCOME

- **Animal Health Impact:** Feed additives that improve gut microbiota can strengthen immune responses and reduce disease incidence.
- **Reproductive & Productive Performance:** A global meta-analysis found that non-antibiotic feed additives can improve weight gain and feed conversion ratios, enhance immune responses, reducing disease incidence and the need for antimicrobial treatment, and promote gut health, which is closely linked to lower methane emissions from enteric fermentation
- **GHG Emissions Impact:** Improved feed efficiency and gut health lower methane emissions per unit of product. For instance, a peer-reviewed study found that supplementation with 3-NOP in beef cattle reduced enteric methane emissions intensity by up to 49.3%.[106]
- **One Health Impact:** Healthier gut microbiomes reduce the risk of pathogen colonization, decreasing the need for antibiotics, which supports efforts to manage AMR.

CASE STUDY

Enhancing livestock health through precision-balanced nutrition

Primary species affected: Cattle

Regions affected: Global

CHALLENGE

Dairy cattle often suffer from metabolic issues during the transition period before and after calving. Disorders such as ketosis and subacute ruminal acidosis are driven by imbalanced nutrition and negative energy balance, and they cause reduced feed efficiency, impaired health (including higher risk of mastitis and lameness) and elevated greenhouse gas emissions through decreased productivity and increased methane output.

Around 65 per cent of dairy cattle diseases occur in this transitional phase, with 75 per cent manifesting in the first month after birth.[107] This has consequences for both the cow and the environment, as subclinical ketosis, one of the most common metabolic disorders in this period, increases farm-level emissions intensity by up to 2.3 per cent.[108]

INTERVENTION

Precision feeding systems can tailor feed rations to each cow based on real-time data on feed intake, milk yield, cow condition, and digestibility. Automated feeders and ration adjustment software allows farmers to integrate by-products and high-digestibility forages for each animal feeding. This highly individualized way of managing the cow's diet has several advantages over standard practices, which rely on batched feeding. For instance, by creating diet profiles that adapt daily, both feed efficiency and cow nutrition can be improved.

OUTCOME

- **Animal Health Impact:** Studies have shown that this method of precision-balanced nutrition reduces metabolic issues that lead to disorders like mastitis and lameness.
- **Reproductive & Productive Performance:** Tailored feeding strategies correlates with increased milk yield per cow and feed conversion and reduced need for replacement animals. Balancing rations also leads to digestibility optimization and lower feed demand per liter of milk.
- **GHG Emissions Impact:** Reducing subclinical ketosis can lower emissions intensity by approximately 2.3% per tonne of milk, while preventing clinical diseases like mastitis may cut emissions intensity by up to 25% per unit of milk.[109]
- **One Health Impact:** Better nutrition strengthens immune function and reduces disease incidence, lowering the need for antimicrobials. This contributes to global efforts to combat AMR.

6. Selective breeding

Overview

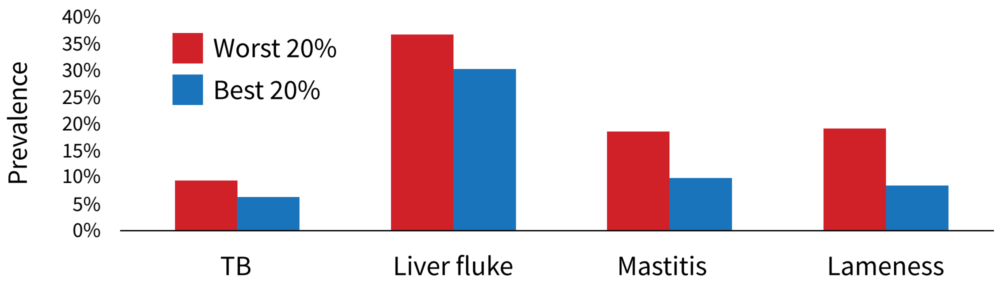
- **Livestock genetics play a key role in determining the predisposition of animals to diseases** and health conditions.
- **Selectively breeding animals for disease resistance results in healthier livestock** and fewer losses, leading to improve herd quality and reduced environmental impact.
- **Genomic selection programmes can also target lower direct methane emissions** from enteric fermentation.

Genetic differences play a role in almost all traits related to animal health, productivity and resilience. This means that, through the systematic use of genetic selection, livestock breeders can identify and propagate animals with superior genetic traits, including reduced susceptibility to disease. This is especially important in low- and middle-income countries where livestock disease prevalence has a disproportionate impact on livelihoods and food security.

By collecting health and performance data across populations of livestock and linking desirable traits – such as stronger immune system responses or lower pathogen loads – to specific genetic markers, breeders can identify disease-resilient animals and cultivate a gradual but cumulative improvement in the health profile of their herd or flock.

Research analyzing the impacts of selective breeding has demonstrated significant benefits in reducing prevalent livestock diseases. For example, a study found the difference in prevalence between animals in the best and worst 20 per cent according to their genetic merit was 26 per cent for tuberculosis, 17 per cent for liver fluke, 58 per cent for lameness and 44 per cent for mastitis.[110]

Figure 3. Variations in disease prevalence based on genetics[111]



Irish researchers found that cows ranked in the top 20% for genetic resistance to disease had significantly lower disease prevalence compared to those in the bottom 20%.

In addition to improved health, livestock with better genetics tend to use inputs more efficiently. Cows with the top 25 per cent of genetic traits, for example, were found to need 44 per cent less antibiotics and five per cent less feed, while producing 35 per cent more milk. This performance translated into an average lifetime profit increase of $869 per cow compared to the inferior genetics group, improving farmers' incomes.[112]

In addition to reducing disease levels and emissions intensity, selective breeding also contributes to reduced total emissions from livestock, as healthier animals emit lower levels of greenhouse gases for a shorter period of time. Selecting animals with inherently lower methane yield, for example, can reduce emissions by as much as 26 per cent over a 10-year period.[113] However, this opportunity is not guaranteed – if breeding programmes focus solely on productivity, without incorporating emissions traits, average methane emissions per animal could increase 13 per cent by 2050, driven by physiological changes like increased feed intake and rumen size.[114]

Genetic selection remains a powerful and underutilized tool for improving animal health, farm profitability, and environmental performance, with the emissions reduction potential from breeding interventions alone estimated at eight per cent. With sufficient data and coordinated breeding strategies, it can play a critical role in sustainable livestock transformation.

CASE STUDY

Leveraging data through the African Dairy Genetic Gains (ADGG) Platform

Primary species affected: Cattle

Regions affected: Africa

CHALLENGE

Selective breeding is a proven tool for improving livestock health, productivity, and environmental performance. However, in many low- and middle-income countries, the lack of reliable data on animal performance can severely limit the ability to make informed breeding decisions. This limits the ability for breeders to produce hardier animals that are resilient to disease and have greater yields, which means a higher emissions intensity for these animals.

INTERVENTION

The African Dairy Genetic Gains (ADGG) Platform was created to address these barriers by collecting, analyzing, and sharing large-scale data on dairy animals across Ethiopia, Kenya, Tanzania, and Uganda, including disease resilience.

The platform combines phenotypic performance data with genomic profiling in smallholder herds to identify and select crossbred bulls and cows suited to local conditions. These superior animals are then disseminated via artificial insemination and community breeding, progressively improving dairy herds across sub-Saharan Africa.

ADGG has registered more than 500,000 animals across 200,000 farms and collected nearly three million records on milk yields, reproductive performance, and health under diverse smallholder conditions. This enables farmers, researchers, and service providers to select genetically superior animals and enhance productivity and resilience. Ultimately, this data-driven approach supports healthier, more productive animals that boost food security, rural incomes, and climate goals.

OUTCOME

- **Animal Health Impact:** By selecting for disease resilience, the ADGG platform enables the breeding of hardier animals better suited to local disease pressures, reducing illness and improving long-term herd health.
- **Reproductive & Productive Performance:** Participating farmers in Tanzania saw a 54% increase in milk yield, while in Ethiopia, early genetic improvements generated an estimated $644,200 in economic gains — both driven by more productive, better-performing animals.
- **GHG Emissions Impact:** Improved genetic performance leads to higher milk yield per animal, reducing emissions intensity by producing more output from fewer animals and less feed — a critical gain in resource-constrained environments.

Implementation:

Barriers and potential solutions

As this report outlines, a vast number of animal health innovations exist to improve livestock health and productivity and reduce emissions (total and intensity). These innovations also offer additional environmental benefits that go beyond climate mitigation, such as reduced land conversion and deforestation as a result of increased productivity, or lower water use resulting from reduced feed requirements. Improved animal health also supports human health through increase food and nutrition security and reduced risk of zoonotic disease. However, the uptake and adoption of these innovations remain unequal around the world with multiple barriers holding back the full scaling up of improved animal health. These include:

Economic and financial constraints

Many livestock producers, especially small-scale farmers, lack access to finance, making investments in improved practices difficult. Some mitigation strategies require high upfront costs, limiting their adoption in low- and middle-income countries, where livestock disease prevalence is higher.

Lack of access to services and infrastructure

Inadequate veterinary services, technical support and extension services hinder the implementation of better health and welfare practices. Similarly, under-developed feed supply chains and market access are limiting factors in resource-poor and remote areas.

Farmer willingness and adoption challenges

Behavioral resistance and lack of awareness or training on new technologies prevents many farmers from adopting them. Long-embedded traditional practices and cultural practices can influence breeding selection, manure use, and dietary choices for livestock.

Policy and regulatory gaps

Many national climate and livestock policies do not include specific mitigation targets, slowing down the adoption of climate-smart interventions. In some cases, regulations and subsidies favor large-scale farming over smallholdings.

Addressing the above barriers requires holistic and innovative solutions that balance incentives and support with the appropriate level of regulation and oversight. Below are some potential steps that countries or other stakeholders could consider. These are only a sample, and other options may be available. Stakeholders should consider their varying local needs and opportunities when taking action.

Financing needs and potential solutions: Scaling up animal health innovations may require diverse financing strategies. Governments, private sector actors, and multilateral institutions all have roles to play in unlocking the necessary capital. Public investment can help de-risk early adoption through grants or subsidies, while blended finance and market-based mechanisms — such as carbon markets or green bonds — may offer new ways to incentivize low-emission livestock practices. Mobilizing private sector resources and fostering public–private partnerships can help ensuring long-term financial sustainability.

Training and capacity building: Enhancing the skills, knowledge, and institutional capacity of livestock producers, veterinarians, and support personnel is fundamental to the success of animal health interventions. Building strong partnerships with agricultural universities and local extension networks can strengthen training programs and research. Integrating scientific knowledge with local practices and ensuring culturally appropriate outreach can improve the relevance and impact of training. Investments in veterinary infrastructure and workforce development are particularly important in underserved regions.

Cooperation with international institutions

Global and regional organizations play a key role in supporting national efforts through technical assistance, policy guidance, and access to knowledge. Institutions such as FAO, WOAH, and CGIAR can help countries design effective animal health strategies and share lessons across borders. Strengthening collaboration with these bodies can accelerate implementation and help ensure efforts are aligned with broader development and climate goals.

Recent examples of successful interventions demonstrate the potential of animal health innovations to work effectively with coordinated action around a common goal. Historic interventions into animal health outbreaks and prolonged diseases have successfully reduced disease burden, improved productivity, and contributed to broader sustainability goals including reduced greenhouse gas emissions.

Credit: ©FAO/Luis Tato

Implementation:

Case Studies: On-the-ground action

To demonstrate how these animal health innovations can translate into real-world impact, the following case studies highlight successful initiatives from across the globe. They feature work at the global, regional, and national levels, in both developed and emerging economies, showing that practical solutions can be scaled up in all kinds of contexts. Each example illustrates not only how improving livestock health supports sustainability, productivity, and rural livelihoods, but also how these interventions can be adapted and adopted to fit local conditions. These efforts have helped to pave the way for more resilient and sustainable livestock systems worldwide.

CASE STUDY

Global eradication of Rinderpest

Rinderpest was a highly contagious viral disease, primarily affecting cattle and buffalo. The fast-spreading disease triggered extensive and prolonged famines, with a 100 per cent death rate in some herds, which significantly hindered agricultural development and undermined food security in many regions of the world before it became the first animal disease to be eradicated in 2011.

A decades-long coordinated effort by the global community combined the development and distribution of vaccines with robust surveillance systems and finance and policy support from national governments and international organizations, including the FAO and WOAH.

Before the development of a vaccine, improved animal health measures such as hygiene protocols, isolation and slaughter of infected animals were commonplace strategies to contain the spread of the disease. Even with a vaccine, eradication efforts encountered significant logistical, technical and institutional barriers, as many of the worst-affected countries lacked the necessary resources and veterinary infrastructure to educate farmers and veterinary paraprofessionals, administer vaccines at scale and monitor, identify, and contain further outbreaks of the disease.

However, by mobilizing political commitment across borders, building community trust and ensuring adequate financing, often through international means, Rinderpest was successfully declared eradicated in 2011. Adjusted for inflation, the cost of eradicating Rinderpest was estimated at $7 billion, dwarfed by the more than $1 billion per year losses suffered by the African livestock industry alone during outbreaks in the 1980s and the potential cost of the disease if it were still prevalent today.[115]

The eradication of Rinderpest serves as a model for future efforts. The Peste des Petits Ruminants Global Eradication Programme, led by the FAO and WOAH, can achieve similar success and further demonstrate how global coordination on animal health can contribute to food system stability, efficient resource use, and emissions reduction.[116]

CASE STUDY

Regional efforts to eliminate Bovine Viral Diarrhoea in Europe

Bovine Viral Diarrhoea (BVD) is a contagious viral disease that poses significant economic and health challenges to farmers and cattle populations. The virus adversely affects reproductive performance in cattle, stunts growth, weakens immune systems, and increases mortality rates among infected animals.

In response to outbreaks in recent years, several European nations, including Germany, Ireland, Scotland and France, have implemented comprehensive eradication programmes designed to eliminate the danger of BVD from national cattle herds.

A cornerstone of these programmes has been early diagnostic testing of newborn calves, typically combined with robust biosecurity measures and targeted vaccination to prevent the spread of the illness. Testing often focuses on the identification and removal of "persistently infected" animals, which act as the primary reservoirs of the virus and continue to spread it to other cattle.

These nationally coordinated strategies successfully aligned public and private stakeholders across the animal health sector, ensuring financial and logistical support for farmers and veterinarians. They demonstrated marked success, reducing prevalence of BVD by as much as 95 per cent in just five years, contributing to improved cattle productivity in these countries.[117]

The elimination of BVD has environmental benefits, as the disease has been linked to increased greenhouse gas emissions intensity from livestock of up to 113 per cent per animal.[118] With an estimated 312 million cases of BVD per year globally, eradication at scale – enabled through diagnostics – can play a significant role in sustainable livestock transformation[119]

CASE STUDY

National action to reduce Trichomoniasis in Argentina

Trichomoniasis is a sexually transmitted disease affecting cattle, which had a significant impact on Argentina's beef industry, particularly in the central province of La Pampa. The disease can reduce pregnancy rates by up to 35 per cent in affected herds, which not only undermines economic returns for producers, but also drastically increase emissions intensity due to prolonged production cycles.[120]

In response to the challenges posed by the disease, the province of La Pampa initiated a mandatory control programme in 2006 to eradicate the disease, which included mandatory annual testing of all non-virgin bulls and the isolation and culling of infected animals.

A challenge for the programme was gaining the cooperation of small and medium scale beef producers in La Pampa, who could suffer economic losses from having to cull valuable breeding bulls. Public-private partnerships delivered diagnostics and veterinary extension services that were instrumental in educating farmers about the long-term productivity and economic gains associated with disease control, thereby increasing participation in the programme.

Between 2008 and 2010, the unprecedented control programme in La Pampa reduced the incidence of bovine trichomoniasis from more than 10 per cent of farms to less than 4 per cent.[121]

By enhancing calving rates, the programme contributed to decreased emissions intensity per unit of beef produced, exemplifying how targeted disease control supported by accessible tools and education for small and medium sized producers can deliver both economic and environmental benefits. Scaling up control efforts to prevent this parasitic disease across Argentina would reduce emissions by an estimated 15–22 per cent, while increasing productivity by 21–31 per cent.[122]

CASE STUDY

Reducing Antimicrobial Use through RENOFARM

Reduce the Need for Antimicrobials on Farms for Sustainable Agrifood Systems Transformation (RENOFARM) is a 10-year global initiative, piloted in countries like Indonesia, Uganda, and Nigeria, aiming to empower farmers with smarter prevention tools to combat Antimicrobial Resistance (AMR) and bolster livestock health and productivity. As climate-focused initiatives seek to scale up sustainable livestock practices, the structure and implementation approach of RENOFARM provides important lessons for success.

For example, in Lampung Province, Indonesia, Farmers Field Schools (FFS) have been established for broiler producers, training facilitators and farmers in semi-closed housing, and educating them on strict hygiene protocols and how to reduce reliance on routine antibiotics. This has led to better biosecurity, improved animal welfare, and a tangible decrease in antimicrobial use as farmers adopted improved practices.

RENOFARM has also convened international training workshops, such as in Nanjing, China, to educate veterinarians and agri-professionals on appropriate and responsible antimicrobial use, biosecurity, vaccine alternatives and prudent livestock management.

The early results for the project are promising, as causes of routine antibiotic dependence have dropped as farmers shift towards the prevention-first methods that the programme is promoting. Participants have been shown to be five times more likely to contact trained animal health professionals for sick animals.[123]

One of the targets of RENOFARM is that 80 per cent of participating countries will contribute data on AMR to the International FAO Antimicrobial Resistance Monitoring IT platform, helping to inform coordinated policies across borders on this danger. The goal for the project is to roll out to 100 countries and train 50 per cent of all animal and plant health professionals and integrate national action plans on AMR to catalyze global agrifood transformation.[124]

While RENOFARM's core focus is reducing the need for antimicrobials, the main intervention areas of the initiatives are centered around providing farm-level support. This is guided by the Farm 5Gs, Good Health Services, Good Production Practices, Good Alternatives, Good Incentives and Good Connection. Its comprehensive approach, grounded in training, capacity building, and international coordination, provides a framework that climate and sustainability efforts can build on to accelerate sustainable transformation in the livestock sector.

Opportunities across the value chain

Leveraging the innovations outlined in this report and learning from the examples of successful interventions require cross-sector efforts. Actions that could be undertaken by stakeholders both public and private to help improve livestock health as a viable pathway towards lower emissions could include, but are not limited to:

Governments and policymakers

- Support the development of appropriate incentive systems
- Strengthen regulatory frameworks such as land efficiency strategies and feed standards
- Enhance and encourage public-private partnerships

Private sector and agri-innovators

- Continue to invest in research and development to find solutions to health and sustainability challenges
- Focus on high-impact projects, including those that enable smallholder access to technology

Financial institutions and investors

- Expand green financing to fix the current imbalance of climate finance for the livestock sector
- Prioritize funds and products for emerging markets and smallholders, such as microfinancing

Research and academic institutions

- Focus on breakthroughs in climate-smart livestock from genetics to nutrition to vaccines
- Bridge the “valley of death” by partnering with the private sector to bring research to application
- Foster knowledge exchange networks through livestock climate solutions hubs

Farmers and livestock producers

- Adopt proven climate-smart livestock solutions
- Engage with research on climate-smart solutions to help guide researchers and product developers
- Leverage digital tools where possible for monitoring and improved efficiency

International organizations and NGOs

- Support knowledge-sharing and capacity-building
- Advocate for climate-smart livestock policies
- Facilitate funding and technical assistance, especially in remote locations

These actions can help better integrate animal health into the toolkit for sustainable livestock transformation across the entire value chain. However, it is critical they are done in close coordination to ensure actions are not siloed and can build upon one another. Organizations like the FAO are uniquely positioned to foster this collaboration.

Conclusion

Animal health is a powerful, yet under-leveraged tool for reducing both total greenhouse gas emissions and emissions intensity in the livestock sector and building resilience against the challenges posed by climate change. Healthier animals are more productive, and when these gains are achieved alongside sustainable herd and resource management, total emissions can fall as well. To unlock the full climate potential of animal health interventions, they must be integrated with broader strategies that manage growth and support long-term sustainability.

As the examples in this report demonstrate, measures to protect against animal disease not only support animal welfare, but also deliver benefits for farmers' incomes, food security, nutritional outcomes and the environment, reinforcing the value of animal health as a core component of One Health.

Throughout the six areas of intervention explored – vaccines, parasite control, biosecurity, diagnostics and digital tools, improved feed and selective breeding – a golden thread can be drawn: when animals are healthier, livestock systems are more efficient, sustainable and resilient.

These interventions span from simple to advanced and innovative methods, offering opportunities for scaling up across income levels and geographies around the world. When combined, they can accelerate impact and have the potential to facilitate a sustainable transformation of the global livestock industry that ensures rising demand for animal products does not come at the cost of a healthy environment.

Innovation alone is not enough. As this report outlines, there are systemic challenges to be overcome in financing, policy, infrastructure, education and cooperation between local, national and international communities and organizations. There are also important limitations in tracking the emissions impact of animal health interventions, due to persistent data gaps and a need for stronger cross-sector collaboration – not least between the animal health, climate and agricultural data systems.

Future reports could expand to cover additional environmental and socio-economic dimensions, offering a more holistic view of the benefits of improved animal health, while also sourcing more case studies from underrepresented areas of Asia and South America. Furthermore, the current focus is primarily on direct on-farm emissions, but upstream impacts, notably those related to feed production and veterinary education and supply chains, also warrant urgent attention.

Animal health innovations can make a vital contribution to transforming food and agriculture systems, including global efforts to reduce greenhouse gas emissions and build climate-resilient food systems that safeguard nutrition, health and livelihoods.

Ensuring that animal health is recognized within this broader agenda, and firmly embedded within a global One Health approach, enables livestock systems to contribute meaningfully to both climate mitigation and adaptation, while continuing to serve as a foundation for food security and economic development.

Endnotes

1 Animal health and Sustainability: A Global Data Analysis (HealthforAnimals, 2021) https://healthforanimals.org/resources/publications/publications/full-report-animal-health-and-sustainability-a-global-data-analysis/

2 Pathways towards lower emissions: A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems (FAO 2023) https://openknowledge.fao.org/server/api/core/bitstreams/a06a30d3-6e9d-4e9c-b4b7-29a6cc307208/content

3 Achieving SDG2 without breaching the 1.5C threshold: A global roadmap (FAO, 2023) https://openknowledge.fao.org/server/api/core/bitstreams/61c1ab4e-32f7-47c4-b267-d6410bb1dac3/content

4 Sustainable livestock transformation: A vision for FAO's work on animal production and health (FAO, 2023) https://openknowledge.fao.org/server/api/core/bitstreams/c0bbe42d-499c-4e4b-a160-de28399e4f97/content

5 FAO. 2023. *Pathways towards lower emissions – A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems.* Rome, Italy, Food and Agriculture Organization. https://doi.org/10.4060/cc9029en

6 Kyriazakis, I., Arndt, C., Aubry, A., Charlier, J., Ezenwa, V.O., Godber, O.F., Krogh, M. ***et al.*** 2024. Improve animal health to reduce livestock emissions: quantifying an open goal. *Proceedings of the Royal Society B: Biological Sciences*, 291(2027): 20240675. https://doi.org/10.1098/rspb.2024.0675

7 WOAH. 2024. *WOAH Vision Paper : Animal health and welfare: cornerstones of sustainable animal farming*. WOAH (World Organisation for Animal Health). https://doi.org/10.20506/woah.3459

8 Bianchi, M., Strid, A., Winkvist, A., Lindroos, A.-K., Sonesson, U. & Hallström, E. 2020. Systematic evaluation of nutrition indicators for use within food LCA studies. Sustainability (Switzerland), 12(21): 1–18. https://doi.org/10.3390/su12218992

9 Chen, W., White, E. & Holden, N.M. 2016. The effect of lameness on the environmental performance of milk production by rotational grazing. Journal of Environmental Management, 172: 143–150. https://doi.org/10.1016/j.jenvman.2016.02.030

10 Mostert, P.F., van Middelaar, C.E., de Boer, I.J.M.M. & Bokkers, E.A.M.M. 2018. The impact of foot lesions in dairy cows on greenhouse gas emissions of milk production. Agricultural Systems, 167: 206–212. https://doi.org/10.1016/j.agsy.2018.09.006

11 Mostert, P.F., Bokkers, E.A.M., de Boer, I.J.M. & van Middelaar, C.E. 2019. Estimating the impact of clinical mastitis in dairy cows on greenhouse gas emissions using a dynamic stochastic simulation model: a case study. Animal, 13(12): 2913–2921. https://doi.org/10.1017/S1751731119001393

12 Özkan, Ş., Vosough Ahmadi, B. & Stott, A.W. 2018. Impact of subclinical mastitis on greenhouse gas emissions intensity and profitability of dairy cows in Norway. Preventive Veterinary Medicine, 150: 19–29. https://doi.org/10.1016/j.prevetmed.2017.11.021

13 A carbon dioxide equivalent or CO2 equivalent, abbreviated as CO2eq is a metric measure used to compare and aggregate emissions from various greenhouse gases. This metric is based on their global-warming potential (GWP) which is a measure of their relative potency over a common time span, usually 100 years (GWP-100). To convert kg of non-CO2 gasses to kg of CO2eq conversions factors are used. These factors are periodically updated and published by IPCC in different assessment reports, reflecting the latest scientific understanding. For instance, GWP-100 conversion factors for livestock systems-pertinent GHGs from the latest assessment (IPCC, 2021) were 27 for non-fossil CH4 and 273 for N2O.

14 Carlson, C.J., Albery, G.F., Merow, C., Trisos, C.H., Zipfel, C.M., Eskew, E.A., Olival, K.J., Ross, N. & Bansal, S. 2022. Climate change increases cross-species viral transmission risk. Nature, 607(7919): 555–562. https://doi.org/10.1038/s41586-022-04788-w

15 FAO, UNEP, WHO & WOAH. 2022. One health joint plan of action (2022–2026): working together for the health of humans, animals, plants and the environment

16 Perry, B.D., Grace, D. & Sones, K. 2013. Current drivers and future directions of global livestock disease dynamics. Proceedings of the National Academy of Sciences, 110(52): 20871–20877.

17 WOAH. 2025. The State of the World's Animal Health 2025. WOAH (World Organisation for Animal Health). https://doi.org/10.20506/woah.3586

18 Mostert, P.F., Bokkers, E.A.M., de Boer, I.J.M. & van Middelaar, C.E. 2019. Estimating the impact of clinical mastitis in dairy cows on greenhouse gas emissions using a dynamic stochastic simulation model: a case study. Animal, 13(12): 2913–2921. https://doi.org/10.1017/S1751731119001393

19 Özkan, Ş., Vosough Ahmadi, B. & Stott, A.W. 2018. Impact of subclinical mastitis on greenhouse gas emissions intensity and profitability of dairy cows in Norway. Preventive Veterinary Medicine, 150: 19–29. https://doi.org/10.1016/j.prevetmed.2017.11.021

20 MacLeod, M., Eory, V., Wint, W., Shaw, A., Gerber, P.J., Cecchi, G., Mattioli, R., Sykes, A. & Robinson, T. 2018. Assessing the Greenhouse Gas Mitigation Effect of Removing Bovine Trypanosomiasis in Eastern Africa. Sustainability, 10(5): 1633. https://doi.org/10.3390/su10051633

21 Lanzoni, L., Reeves, M.C., Waxenberg, K., Ramsey, R., Atzori, A.S., Bell, J., Rees, R.M., Vignola, G. & Dwyer, C.M. 2025. The carbon cost of impaired welfare on sheep farms. animal, 19(2): 101390. https://doi.org/10.1016/j.animal.2024.101390

22 MacLeod, M., Eory, V., Wint, W., Shaw, A., Gerber, P.J., Cecchi, G., Mattioli, R., Sykes, A. & Robinson, T. 2018.

Assessing the Greenhouse Gas Mitigation Effect of Removing Bovine Trypanosomiasis in Eastern Africa. Sustainability, 10(5): 1633. https://doi.org/10.3390/su10051633
23 Capper, J.L. 2023. The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production. One Health Outlook, 5(1): 17. https://doi.org/10.1186/s42522-023-00089-y
24 FAO. 2023. Pathways towards lower emissions – A global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems. Rome, Italy, Food and Agriculture Organization. https://doi.org/10.4060/cc9029en
25 IPCC. 2019. Chapter 10: Emissions from livestock and manure management. Geneva, Switzerland, Intergovernmental Panel on Climate Change.
26 IPCC, (International Panel on Climate Change). 2006. 2006 IPCC Guidelines for National Greenhouse Gas inventories - Chapter 10: Emissions from livestock and manure management. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
27 Özkan, Ş., Teillard, F., Lindsay, B., Montgomery, H., Rota, A., Gerber P., Dhingra M. and Mottet, A. 2022. The role of animal health in national climate commitments. Rome, FAO. https://doi.org/10.4060/cc0431en
28 Capper, J.L.2023.The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production.One Health Outlook, 5(1):
29 FAO. 2024. Greenhouse gas emissions from agrifood systems – Global, regional and country trends, 2000–2022. FAOSTAT Analytical Brief Series, No. 94. Rome. https://openknowledge.fao.org/handle/20.500.14283/cd3167en
30 Animal health and Sustainability: A Global Data Analysis (HealthforAnimals, 2021) https://healthforanimals.org/resources/publications/publications/full-report-animal-health-and-sustainability-a-global-data-analysis/
31 Ibid
32 Global quest for vaccine to cut methane in cattle (2024) https://www.pirbright.ac.uk/news/global-quest-vaccine-cut-methane-cattle
33 Özkan, Ş., Teillard, F., Lindsay, B., Montgomery, H., Rota, A., Gerber P., Dhingra M. and Mottet, A. 2022. The role of animal health in national climate commitments. Rome, FAO. https://doi.org/10.4060/cc0431en
34 Capper JL. The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production. One Health Outlook. 2023 Dec 8;5(1):17. doi: 10.1186/s42522-023-00089-y. PMID: 38062496; PMCID: PMC10704630.
35 Center for Food Security and Public Health. Highly Pathogenic Porcine Reproductive and Respiratory Syndrome Virus (HP-PRRSV). College of Veterinary Medicine, Iowa State Univ., [ca.2015]. PDF file, https://www.cfsph.iastate.edu/pdf/shic-factsheet-highly-pathogenic-prrsv#
36 Tousignant, Steven J.P., et al. “Temporal and Spatial Dynamics of Porcine Reproductive and Respiratory Syndrome Virus Infection in the United States.” American Journal of Veterinary Research, vol.76, no.1, Jan.2015, pp.70–76. doi:10.2460/ajvr.76.1.70. PDF file, https://avmajournals.avma.org/view/journals/ajvr/76/1/ajvr.76.1.70.pdf.
37 Li, C., Zhao, J., Li, W. et al. Prevalence and genetic evolution of porcine reproductive and respiratory syndrome virus in commercial fattening pig farms in China. *Porc Health Manag* 10, 5 (2024). https://doi.org/10.1186/s40813-024-00356-y
38 Porcine Reproductive and Respiratory Syndrome (MSD Manual, 2024) https://www.msdvetmanual.com/generalized-conditions/porcine-reproductive-and-respiratory-syndrome/porcine-reproductive-and-respiratory-syndrome
39 Growing Losses from PRRS Cost Pork Producers $1.2 Billion Per Year, New Study Shows (Iowa State University, 2024) https://research.iastate.edu/2024/07/30/growing-losses-from-prrs-cost-pork-producers-1-2-billion-per-year-new-study-shows
40 Vaccination of piglets with PRRSV-MLV promotes nursery stability and reduction of mortality (HIPRA, 2024) https://prrscontrol.com/wp-content/uploads/2024/06/Piglet-vaccination-with-PRRSV-MLV-promotes-nursery-stability-and-mortality-reduction.pdf
41 Park C, Seo HW, Kang I, Jeong J, Choi K, Chae C.2014.A New Modified Live Porcine Reproductive and Respiratory Syndrome Vaccine Improves Growth Performance in Pigs under Field Conditions. Clin Vaccine Immunology. https://doi.org/10.1128/CVI.00377-14
42 Jiwoon Jeong, Seeun Kim, Kee Hwan Park, Ikjae Kang, Su-Jin Park, Changhoon Park, Chanhee Chae, Evaluation of the effect of a porcine reproductive and respiratory syndrome (PRRS) modified-live virus vaccine on sow reproductive performance in endemic PRRS farms, Veterinary Microbiology, https://doi.org/10.1016/j.vetmic.2017.07.016.
43 Capper JL. The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production. One Health Outlook. 2023 Dec 8;5(1):17. doi: 10.1186/s42522-023-00089-y. PMID: 38062496; PMCID: PMC10704630.
44 Spickler, Anna Rovid. *Peste des Petits Ruminants*. Center for Food Security & Public Health, Iowa State University www.cfsph.iastate.edu/Factsheets/pdfs/peste_des_petits_ruminants.pdf
45 https://onlinelibrary.wiley.com/doi/full/10.1002/vms3.300
46 Peste des petits ruminants (WOAH, 2024) https://rr-asia.woah.org/en/projects/peste-des-petits-ruminants-ppr/
47 Progress towards Eradication of Peste des Petits Ruminants through Vaccination (Zhao et al, 2021) https://pubmed.ncbi.nlm.nih.gov/33466238/
48 Gurrappanaidu G, Subbanna NKG, Wanyoike F, Bahta S, Reddy YR, Bardhan D, Vinayagamurthy B, Vijayalakshmy K, Habibur R. Assessment of Vaccination Impact in PPR-Control Program Implemented in Southern States of India: A System Dynamics Model Approach. *Viruses*. 2025; 17(1):23. https://doi.org/10.3390/v17010023
49 Aboah, J., Apolloni, A., Duboz, R., Wieland, B., Kotchofa, P., Okoth, E. and Dione, M. 2023. Ex-ante impact of peste des petits ruminants control on micro and macro socioeconomic indicators in Senegal: A system

dynamics modelling approach. PLOS ONE 18(7): e0287386.
50 Thombare, N. N., and Mukesh K. Sinha. "Economic Implications of Peste des Petits Ruminants (PPR) Disease in Sheep and Goats: A Sample Analysis of District Pune, Maharashtra." Agricultural Economics Research Review, vol. 22, no. 1, July 2009, DOI:10.22004/ag.econ.57469. *Ageconsearch*, https://ageconsearch.umn.edu/record/57469/
51 Lanzoni, L, Reeves, MC, Waxenberg, K, Ramsey, R, Atzori, AS, Bell, J, Rees, RM, Vignola, G & Dwyer, CM 2025, 'The carbon cost of impaired welfare on sheep farms', Animal , vol. 19, 101390, pp. 1-11. https://doi.org/10.1016/j.animal.2024.101390
52 FAO. 2016. Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment. Livestock Environmental Assessment and Performance Partnership. FAO, Rome, Italy.
53 The Economic Impact of Parasitism from Nematodes, Trematodes and Ticks on Beef Cattle Production (Strydom et al, 2023) https://pmc.ncbi.nlm.nih.gov/articles/PMC10215612/
54 Global and regional prevalence of helminth infection in chickens over time: a systematic review and meta-analysis (Shifaw et al, 2021) https://pmc.ncbi.nlm.nih.gov/articles/PMC8047976/
55 FAO. 2025. Guidelines for sustainable tick control and acaricide resistance management in livestock. FAO Animal Production and Health Guidelines, No. 38. Rome. https://doi.org/10.4060/cd4964en
56 Shifaw A, Feyera T, Walkden-Brown SW, Sharpe B, Elliott T, Ruhnke I. Global and regional prevalence of helminth infection in chickens over time: a systematic review and meta-analysis. Poult Sci. 2021 May;100(5):101082. doi: 10.1016/j.psj.2021.101082. Epub 2021 Mar 4. PMID: 33813325; PMCID: PMC8047976.
57 Ibid
58 N.J. Fox, L.A. Smith, J.G.M. Houdijk, S. Athanasiadou, M.R. Hutchings, Ubiquitous parasites drive a 33% increase in methane yield from livestock, International Journal for Parasitology, Volume 48, Issue 13, 2018, https://doi.org/10.1016/j.ijpara.2018.06.001.
59 Ezenwa VO, Civitello DJ, Barton BT, Becker DJ, Brenn-White M, Classen AT, Deem SL, Johnson ZE, Kutz S, Malishev M, Penczykowski RM, Preston DL, Vannatta JT, Koltz AM. Infectious Diseases, Livestock, and Climate: A Vicious Cycle? Trends Ecol Evol. 2020 Nov;35(11):959-962. doi: 10.1016/j.tree.2020.08.012. Epub 2020 Oct 7. PMID: 33039158; PMCID: PMC7539894.
60 The role of animal health in national climate commitments (FAO, 2022) https://openknowledge.fao.org/server/api/core/bitstreams/d376d022-3ecd-4bc9-a842-491d796d635e/content
61 Hayward AD, Skuce PJ, McNeilly TN. The influence of liver fluke infection on production in sheep and cattle: a meta-analysis. Int J Parasitol. 2021 Oct;51(11):913-924. doi: 10.1016/j.ijpara.2021.02.006. Epub 2021 Apr 24. PMID: 33901437.
62 The role of animal health in national climate commitments (FAO, 2022) https://openknowledge.fao.org/server/api/core/bitstreams/d376d022-3ecd-4bc9-a842-491d796d635e/content
63 Reduction in Greenhouse Gas Emissions Associated with Worm Control in Lambs (Kenyon et al, 2013) https://www.mdpi.com/2077-0472/3/2/271
64 Spickler, Anna Rovid. *Trypanosomiasis, African (Nagana, Tsetse Disease, Sleeping Sickness)*. Center for Food Security & Public Health, Iowa State University, May 2023, https://www.cfsph.iastate.edu/Factsheets/pdfs/trypanosomiasis_african.pdf
65 Getie Mulat, Moges Maru, Zewdu Seyoum Tarekegn, Haileyesus Dejene, A systematic review and meta-analysis on prevalence of bovine trypanosomosis in East Africa, Parasite Epidemiology and Control, Volume 26, 2024, https://doi.org/10.1016/j.parepi.2024.e00371.
66 Cecchi, G., Paone, M., de Gier, J. and Zhao, W. 2024. *The continental atlas of the distribution of tsetse flies in Africa*. PAAT Technical and Scientific Series, No. 12. Rome, FAO. https://doi.org/10.4060/cd2022en
67 Boulangé, Alain, et al. "The COMBAT project: controlling and progressively minimizing the burden of vector-borne animal trypanosomosis in Africa." *Open Research Europe 2* (2022): 67.
68 Cecchi et al., 2025. Disease intelligence and modelling for progressive control of animal trypanosomosis in Africa. Trends in Parasitology. https://doi.org/10.1016/j.pt.2025.07.003
69 Diall, Oumar, et al. "Developing a progressive control pathway for African animal trypanosomosis." *Trends in parasitology* 33.7 (2017): 499-509.
70 FAO. 2022. Expert consultation on the sustainable management of parasites in livestock challenged by the global emergence of resistance - Part 2: African animal trypanosomosis and drug resistance – a challenge to progressive, sustainable disease control, 9–10 November 2021. FAO Animal Production and Health Report No. 18. Rome. https://doi.org/10.4060/cc2988en
71 Bauer B, Amsler-Delafosse S, Kaboré I, Kamuanga M. Improvement of cattle productivity through rapid alleviation of African animal trypanosomosis by integrated disease management practices in the agropastoral zone of Yalé, Burkina Faso. Trop Anim Health Prod. 1999 Apr;31(2):89-102. doi: 10.1023/a:1005115707181. PMID: 10371008.
72 Swallow, B.M. 2000. Impacts of trypanosomiasis on African agriculture. PAAT Technical and Scientific Series, No. 2. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/x4755en
73 Assessing the Greenhouse Gas Mitigation Effect of Removing Bovine Trypanosomiasis in Eastern Africa (2018) https://www.mdpi.com/2071-1050/10/5/1633
74 Risk factors for foot-and-mouth disease in sedentary livestock herds in selected villages in four regions of Bhutan (Dukpa, et al, 2011) https://www.tandfonline.com/doi/abs/10.1080/00480169.2011.552852
75 Capper, J.L.2023.The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production.One Health Outlook, 5(1): 17.https://doi.org/10.1186/s42522-023-00089-y
76 Improvements in swine herd biosecurity reduce the incidence risk of porcine reproductive and respiratory syndrome virus in breeding herds in the Midwestern United States (Dee et al, 2023) https://avmajournals.

avma.org/view/journals/javma/262/4/javma.23.08.0437.xml
77 Capper, J.L.2023.The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production.One Health Outlook, 5(1): 17.https://doi.org/10.1186/s42522-023-00089-y
78 Alocilla-Velásquez O, Monti G, Saatkamp H, Mourits M, Lindberg A, Widgren S. Herd-Level Modeling of Bovine Viral Diarrhea Virus (BVDV) Transmission in Cattle Herds in Southern Chile: Linking Within and Between-Herd Dynamics. Transbound Emerg Dis. 2024 Oct 28;2024:4734277. doi: 10.1155/2024/4734277. PMID: 40303155; PMCID: PMC12017151.
79 Su N, Wang Q, Liu H-Y, Li L-M, Tian T, Yin J-Y, Zheng W, Ma Q-X, Wang T-T, Li T, Yang T-L, Li J-M, Diao N-C, Shi K and Du R (2023) Prevalence of bovine viral diarrhea virus in cattle between 2010 and 2021: A global systematic review and meta-analysis. *Front. Vet. Sci.* 9:1086180. doi: 10.3389/fvets.2022.1086180
80 A systems-LCA approach to modelling the impact of improvements in cattle health on greenhouse gas emissions https://www.cabidigitallibrary.org/doi/pdf/10.5555/20153221318
81 Eradication of bovine viral diarrhea virus in Germany—Diversity of subtypes and detection of live-vaccine viruses (2017) https://www.sciencedirect.com/science/article/abs/pii/S0378113517304996
82 Alocilla-Velásquez O, Monti G, Saatkamp H, Mourits M, Lindberg A, Widgren S. Herd-Level Modeling of Bovine Viral Diarrhea Virus (BVDV) Transmission in Cattle Herds in Southern Chile: Linking Within and Between-Herd Dynamics. Transbound Emerg Dis. 2024 Oct 28;2024:4734277. doi: 10.1155/2024/4734277. PMID: 40303155; PMCID: PMC12017151.
83 How Dairy Cattle Health Impacts Greenhouse Gas Emissions: Chile, Kenya & UK (GRA, GDP, DSF, 2022) https://www.dairysustainabilityframework.org/wp-content/uploads/2022/06/GHG-Dairy-Health-Leaflet-v2.pdf
84 Krebs I, Zhang Y, Wente N, Leimbach S, Krömker V. Severity of Clinical Mastitis and Bacterial Shedding. Pathogens. 2023; 12(9):1098. https://doi.org/10.3390/pathogens12091098
85 Krishnamoorthy P, Goudar AL, Suresh KP, Roy P. Global and countrywide prevalence of subclinical and clinical mastitis in dairy cattle and buffaloes by systematic review and meta-analysis. Res Vet Sci. 2021 May;136:561-586. doi: 10.1016/j.rvsc.2021.04.021. Epub 2021 Apr 18. PMID: 33892366.
86 Ibid
87 The role of animal health in national climate commitments (FAO, 2022) https://openknowledge.fao.org/server/api/core/bitstreams/d376d022-3ecd-4bc9-a842-491d796d635e/content
88 Economics of Measuring Costs Due to Mastitis-Related Milk Loss (Holland et al. 2015) https://econpapers.repec.org/paper/agsaaea15/205638.htm
89 The role of animal health in national climate commitments (FAO, 2022) https://openknowledge.fao.org/server/api/core/bitstreams/d376d022-3ecd-4bc9-a842-491d796d635e/content
90 Ferronato G, Simonetto A, Gilioli G, Zecconi A. Modeling Mastitis Risk Management Effects on Dairy Milk Yield and Global Warming Potential. Animals (Basel). 2024 Dec 28;15(1):50. doi: 10.3390/ani15010050. PMID: 39794993; PMCID: PMC11718989.
91 The impact of subclinical ketosis in dairy cows on greenhouse gas emissions of milk production (Mostert et al, 2018) https://www.sciencedirect.com/science/article/abs/pii/S0959652617323119?via%3Dihub
92 Technological Tools for the Early Detection of Bovine Respiratory Disease in Farms (Puid et al, 2022) https://pmc.ncbi.nlm.nih.gov/articles/PMC9558517/?utm
93 Ibid.
94 Ibid.
95 The potential of diagnostic point-of-care tests (POCTs) for infectious and zoonotic animal diseases in developing countries: Technical, regulatory and sociocultural considerations (Hobbs et al, 2020) https://pmc.ncbi.nlm.nih.gov/articles/PMC8359337/
96 Economic Benefits of Diagnostic Testing in Livestock: Anaplasmosis in Cattle (Railey et al, 2021) https://pmc.ncbi.nlm.nih.gov/articles/PMC8369028/
97 Department for Environment, Food and Rural Affairs. *Modelling the Impact of Controlling Endemic Cattle Diseases* (Project AC0120), 1 Oct. 2011–. Defra Science and Research Portal, https://randd.defra.gov.uk/ProjectDetails?ProjectID=17791&FromSearch=Y&Publisher=1&SearchText=AC0120&SortString=ProjectCode&SortOrder=Asc&Paging=10
98 New RVC research reveals extent and progression of bovine respiratory disease in UK dairy calves (2025 https://www.rvc.ac.uk/research/programmes/livestock-production-and-health/news/new-rvc-research-reveals-extent-and-progression-of-bovine-respiratory-disease-in-uk-dairy-calves
99 Eddicks M, Feicht F, Beckjunker J, Genzow M, Alonso C, Reese S, Ritzmann M, Stadler J. Monitoring of Respiratory Disease Patterns in a Multimicrobially Infected Pig Population Using Artificial Intelligence and Aggregate Samples. Viruses. 2024; 16(10):1575. https://doi.org/10.3390/v16101575
100 Lameness detection in dairy cows: use of sensors to automatically register changes in locomotion or behaviour (2015) https://www.mdpi.com/2076-2615/5/3/388
101 Eddicks M, Feicht F, Beckjunker J, Genzow M, Alonso C, Reese S, Ritzmann M, Stadler J. Monitoring of Respiratory Disease Patterns in a Multimicrobially Infected Pig Population Using Artificial Intelligence and Aggregate Samples. *Viruses*. 2024; 16(10):1575. https://doi.org/10.3390/v16101575
102 Severe below-maintenance feed intake increases methane yield from enteric fermentation in cattle (Goopy et al, 2020) https://pubmed.ncbi.nlm.nih.gov/32209141/
103 Modelling the effect of feeding management on greenhouse gas and nitrogen emissions in cattle farming systems (Ouatahar et al, 2021) https://www.sciencedirect.com/science/article/pii/S0048969721009992
104 A meta-analysis of effects of 3-nitrooxypropanol on methane production, yield, and intensity in dairy cattle (Kebreab et al, 2023) https://www.sciencedirect.com/science/article/pii/S002203022200710X
105 Lily Liu, Pengfei Wang, Songlin Liu, Min Yan, Qin Zhang, Emily Clark, Jinhai Wang, Meta-analyses of

the global impact of non-antibiotic feed additives on livestock performance and health, Journal of Advanced Research, 2025, https://doi.org/10.1016/j.jare.2025.03.009.
106 Araújo TLR, Rabelo CHS, Cardoso AS, Carvalho VV, Acedo TS, Tamassia LFM, Vasconcelos GSFM, Duval SM, Kindermann M, Gouvea VN, Fernandes MHMR, Reis RA. Feeding 3-nitrooxypropanol reduces methane emissions by feedlot cattle on tropical conditions. J Anim Sci. 2023 doi: 10.1093/jas/skad225. PMID: 37402612; PMCID: PMC10358221.
107 Relationship between dairy cow health and intensity of greenhouse gas emissions (2024) https://pmc.ncbi.nlm.nih.gov/articles/PMC10967422/
108 The impact of subclinical ketosis in dairy cows on greenhouse gas emissions of milk production (Mostert et al, 2018) https://www.sciencedirect.com/science/article/abs/pii/S0959652617323119?via%3Dihub
109 Estimating the impact of clinical mastitis in dairy cows on greenhouse gas emissions using a dynamic stochastic simulation model: a case study (2019) https://www.researchgate.net/publication/333864575_Estimating_the_impact_of_clinical_mastitis_in_dairy_cows_on_greenhouse_gas_emissions_using_a_dynamic_stochastic_simulation_model_A_case_study
110 Breeding for improved animal health (Twomey and Ring, 2019) https://teagasc.ie/wp-content/uploads/2025/05/Breeding-for-improved-animal-health.pdf
111 Ibid
112 New study shows genetically superior cows can be more sustainable and productive https://www.zoetisus.com/news-and-media/new-study-shows-genetically-superior-cows-can-be-more-sustainable-and-productive/
113 Genetic parameters for predicted methane production and potential for reducing enteric emissions through genomic selection (de Haas et al, 2011) https://pubmed.ncbi.nlm.nih.gov/22118100/
114 Selective breeding as a mitigation tool for methane emissions from dairy cattle (de Haas et al, 2021) https://pubmed.ncbi.nlm.nih.gov/34246599/
115 Cattle scourge no more: The eradication of rinderpest and its lessons for global health campaigns (Youde, 2013) https://www.jstor.org/stable/43287267
116 Peste des Petits Ruminants Global Eradication Programme (PPR-GEP) (FAO, 2025) https://www.fao.org/animal-health/our-programmes/peste-des-petits-ruminants-global-eradication-programme-(ppr-gep)/en
117 Eradication of bovine viral diarrhea virus in Germany-Diversity of subtypes and detection of live-vaccine viruses (Wernike et al, 2017) https://pubmed.ncbi.nlm.nih.gov/28888645/
118 Healthy livestock produce sustainable food (Capper et al, 2019) https://www.msd-animal-health-hub.co.uk/sites/default/files/content/media/healthy_livestock_whitepaper.pdf
119 Prevalence of bovine viral diarrhea virus in cattle between 2010 and 2021: A global systematic review and meta-analysis (Su et al, 2023) https://www.frontiersin.org/journals/veterinary-science/articles/10.3389/fvets.2022.1086180/full
120 Bovine Trichomoniasis (Mohammed et al. 2022) https://uniquescientificpublishers.com/wp-content/uploads/2023/oht-v3/107-113.pdf?utm
121 Zero inflated count regression for one year prediction of bovine trichomonosis in a compulsory control plan in La Pampa, Argentine (Oyhenart, 2020) https://www.sciencedirect.com/science/article/abs/pii/S2405939020300083
122 The role of animal health in national climate commitments (FAO, 2022) https://openknowledge.fao.org/server/api/core/bitstreams/d376d022-3ecd-4bc9-a842-491d796d635e/content
123 Reduce the Need for Antimicrobials on Farms for Sustainable Agrifood Systems Transformation (2020) https://rr-asia.woah.org/app/uploads/2025/03/200FBE1.pdf
124 Reduce the Need for Antimicrobials on Farms for Sustainable Agrifood Systems Transformation (2025) https://www.fao.org/antimicrobial-resistance/background/fao-role/renofarm/en
125 Feeding efficiency gains can increase the greenhouse gas mitigation potential of the Tanzanian dairy sector (Hawkins et al, 2018) https://pmc.ncbi.nlm.nih.gov/articles/PMC7893068/