Report

CGIAR Initiative on Livestock and Climate

Livestock and Climate Change: Outlook for a more sustainable and equitable future

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Cows walk along an irrigation canal in Niolo, Mali (photo credit: ILRI/Stevie Mann)

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Executive Summary

1. The livestock sector will need to simultaneously meet future consumer demand while supporting net zero targets by 2050, survive increasing frequency and severity of climate change hazards, and achieve outcomes for water, biodiversity, social resilience and economic development.

2. Climate change therefore requires a new trajectory for the development of the livestock sector. The economic role of livestock may shift significantly, and we need to anticipate a just transition of livestock farmers to other livelihood activities.

3. Trends in livestock demand and supply under climate change are likely to become more uncertain and equity and productivity gaps are likely to intensify in the coming decades. Although industrialised systems can better invest in the feed and adaptations and mitigation measures needed under climate change than smallholders' systems, livestock are critical for smallholders' livelihoods and food security, and we need to anticipate the wider range of interventions that may be needed to increase resilience in such systems.

4. Future livestock and climate development needs to be planned and implemented in a cross-sectoral way. The multi-dimensional importance of livestock to the livelihoods of at least 1.3 billion people globally has not yet been reflected in development or climate assistance, research focus or the data landscape.

5. Under climate change, there are no one-size-fits-all policy and technological responses, nor are there any silver bullets. There are multiple, often competing discourses around the climate-livestock-livelihood nexus and responses need to be appropriate for local contexts while contributing to national and global targets.

6. Many management options are available to help livestock farmers in lower-income countries adapt to climate change, including diversification of livestock species and breeds; integration of livestock with forestry, crop and aquaculture production; improving livestock diets; modifying animal health and heat stress management strategies; and changing the timing and location of farm operations.

7. Institutional, policy and technological opportunities for increasing livestock farmers' adaptive capacity include preserving livestock mobility traditions in pastoral lands; assistance with destocking and restocking before and after drought; developing new product markets to satisfy consumer demand; promoting wider use of index-based insurance products and other risk transfer mechanisms; and enhancing farmers' effective use of extension information using social media and digital platforms.

8. The viability of options to adapt and increase adaptive capacity is highly dependent on local contexts that are often characterized by capital, land and labour constraints and limited accessibility and knowledge. And in the face of longer-term climate change, the limits to the effectiveness of such options are often unknown.

9. Additional management options are available to help livestock farmers in lower-income countries mitigate greenhouse gas emissions or sequester carbon, including intensified production with fewer animal numbers, managing herd composition, shifting to lower-emission types of livestock, silvopastoralism, grassland restoration, avoided burning of grasslands, and low-emission breed selection. Along the supply chain, more efficient and renewable energy in the cold chain is a major option for mitigation. While additional measures such as feed additives, manure management or alternative proteins also can reduce methane, these technologies are not yet available, affordable or relevant to many lower-income farmers. Vaccines and manipulation of the rumen microbiome are promising technologies for the future.

10. Methane is a strategic greenhouse gas emission to reduce because of its quick action on the climate as a short-lived climate pollutant. As a major contributor to global methane, the livestock sector is critical to meeting global mitigation targets, including in LMICs. As absolute reduction of methane emissions in livestock is necessary to reduce climate change, more greenhouse-gas-efficient livestock products alone are not enough to meet climate targets. National investment and overseas development assistance that fund the livestock sector without concomitant reductions in emissions only exacerbate climate change. Targeting only higher income countries could increase livestock emissions in lower-income countries.

11. Reducing livestock emissions requires finance, policy, technical support, R&D and rigorous accounting of emissions to incentivize new practices at large scales. Countries and corporations need to move from pledges and commitments to incentives and action through policy targets and disclosure requirements, sustainability-linked finance, and development assistance for new technical measures. R&D for affordable technological innovation is necessary if animal numbers are to be retained or grow. Rigorous accounting is necessary to track progress at the food and farm level.

12. Without rigorous monitoring and information systems, there is little chance of being able to identify in a timely way when course corrections to local food systems will be needed, and holding different food system actors to account will be very difficult. For adaptation, integrated information systems for climate forecasting, early warning systems and humanitarian assistance, especially for prolonged drought, are needed.

Boran cattle grazing at Kapiti ranch in Kenya (photo credit: ILRI).

1. Introduction: Challenges and priorities for the livestock sector under climate change

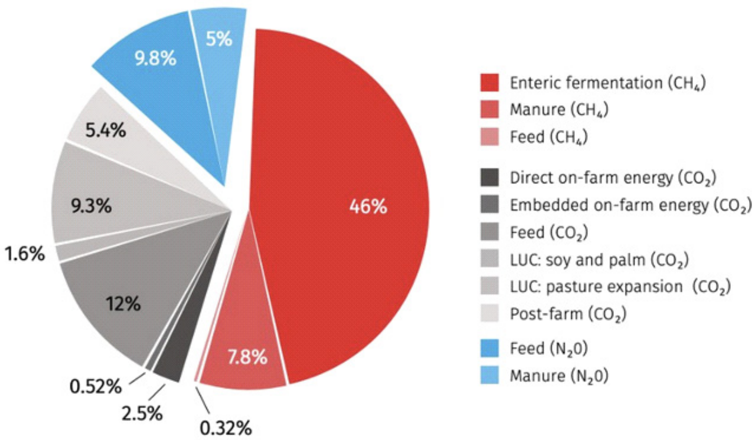
This policy brief summarizes the outlook for livestock policy and investment in the face of climate change, drawing on research conducted by the CGIAR Livestock and Climate Initiative 2022 to 2024. The purpose of the Initiative was to address the “double burden” that climate change poses for livestock production in Africa and Latin America: livestock production is both highly vulnerable to climate change as well as one of the largest sources of greenhouse gases. The Initiative identified, co-created and delivered innovations to help producers, businesses and governments adapt livestock agrifood systems to climate change and reduce greenhouse gas emissions. Topics ranged from developing on-farm technologies for locally led adaptation and digitally enabled climate risk management services to analysis of opportunities to enhance women and youth’s livelihood options, climate security, environmental impacts of livestock, and finance and policy for resilient, low-emission livestock production. Accompanying this policy brief as companion pieces on specific topics are additional policy briefs synthesizing these results (see Box 1). Although the Initiative’s research focused on eight countries-- Colombia, Ethiopia, Guatemala, Kenya, Mali Senegal, Tanzania and Tunisia--this outlook brief takes a global perspective, with an emphasis on low- and middle-income countries and smallholder livestock farmers.

Box 1: Companion briefs accompanying this Outlook Report

Brief 1. Climate, Conflict and Security in Global Livestock Systems
Brief 2. Supporting Collaborative Action for Sustainable Solutions: Locally-Led Adaptation as a Policy Instrument for Climate Change Adaptation Practices
Brief 3. Policy and Institutions Needed to Transform Livestock Systems Under Climate Change
Brief 4. Reducing the Environmental Footprint of Livestock Production
Brief 5. Socially Inclusive and Equitable Approaches for Resilient Livestock Systems
Brief 6. Improved Forages for Increased Livestock Productivity and Climate Adaptation and Mitigation

Development of the livestock sector under climate change faces three challenges. It must meet future consumer demand while supporting net zero targets by 2050, survive increasing frequency and severity of climate change hazards, and achieve outcomes for water, biodiversity, social resilience and economic development. All require investment now. Livestock is the number one source of emissions in the food, agricultural and land sectors. Globally, the 4 billion animals used for meat, dairy and other products contribute 14.5% of anthropogenic greenhouse gas emissions (7.1 billion tons of CO2e, referenced to 2005). Emissions from the animals and their substantial environmental footprint include methane, carbon dioxide and nitrous oxide.

Climate change in turn is expected to affect the future productivity of livestock, both in terms of gradual warming and increasing variability and frequency of extreme events. Unlike crop farmers, livestock farmers cannot decide to not plant; but they can sell and then restock animals before and after a flood or drought, for example. Yet this cycle does not solve the problem. The thresholds for livestock resilience under climate change are not completely understood. A temperature increase of 4°C above pre-industrial levels will be well beyond the coping range of all domesticated animals, and probably humans too. Even a 2°C rise, which appears to be increasingly unavoidable, will heavily modify the agricultural landscape globally, with substantial reductions in crop and livestock productivity in many low-altitude, low-latitude locations in the absence of effective adaptation. For the many vulnerable people who live in these areas and depend on agriculture for livelihoods and food security, climate change is already increasing the inequity gap.



Theme	Interventions	Reduction potential (%)
Demand	Changes in consumption of TASF	4
	Reducing food loss and waste	5
Animal and feed management	Productivity increases	20
	Breeding	8
	Rumen manipulation	5
	Feed and nutrition improvements	12
	Improved animal health	10
Soils	Carbon sequestration	7
Supply chain	Circular bioeconomies	5
	Energy use	2
Manure	Manure management	2

Figure 1: Meat supply chain emissions and mitigation options
Source: https://openknowledge.fao.org/server/api/core/bitstreams/a06a30d3-6e9d-4e9c-b4b7-29a6cc307208/content (Figures 5 & B2.2)

The livestock economy will likely shift under climate change. Livestock presently contribute 40% of the global value of agricultural output, 33% of protein consumption and support the livelihoods and food and nutrition security of almost 1.3 billion people. The sector is expected to grow significantly in the next three decades. The global beef market is projected to grow from USD 415 billion in 2022 to USD 604 billion by 2029, and the global dairy market to grow from USD 827 billion in 2020 to USD 1128 billion by 2026. Projected demand varies substantially between the Global North and South, as do climate change impacts.

Managing livestock to meet economic, livelihood and climate change goals will be increasingly challenging because of the many environmental and social outcomes related to raising animals. Livestock have a large overall environmental footprint, using one-third of global arable land for feed and 30% of fresh water for rearing and processing livestock products. Animal waste is a major contributor to air and water pollution. Livestock constitute 94% of non-human mammal biomass. Socially, animals often act as economic safety nets and play critical cultural roles, for example among pastoralists in East Africa. From a dietary and health perspective, livestock are critical sources of nutrition in many parts of the world, although overconsumption of some meats has also been linked to cancer and disease.

Livestock policy in the Global South mostly focuses on services to improve animal productivity, local livelihoods, and food security, with major meat producing countries in Latin America (Brazil, Argentina) also focused on exports and sustainability. Systematic alignment of livestock policies with climate change targets and policies is needed. The existing policy agenda for livestock is extensive and often fragmented. At the national level, policies range from animal productivity (animal health, disease prevention and monitoring, breeding services, feed production, animal nutrition) and standards for animal management and welfare, to trade and market access, environmental management (manure, water quality, air pollution, land restoration) and health and biosecurity. At the continental level in Africa, the African Union has adopted the Livestock Development Strategy for Africa (LiDeSA) 2015 – 2035 which aims to transform the African livestock sector into one that is sustainable and competitive while addressing the challenges of climate change. Climate change policies include national climate strategies, nationally determined contributions, national adaptation plans and long-term strategies. While many of these have livestock targets included, ensuring that corresponding national and regional livestock policies and strategies align with the climate policy targets is urgently needed.

The livestock sector is both part of the problem and part of the solution. The livestock sector is a major user of land and emitter of greenhouse gases, while at the same time providing food with high quality protein and high levels of micronutrients and incomes and livelihoods for hundreds of millions of people, particularly in lower- and middle-income countries (LMICs). Livestock account for around half of the technical mitigation potential of the agriculture, forestry and land-use sectors; but the economic potential is a small fraction of what is technically possible because of the many competing economic, environmental, socio-cultural and equity objectives that impinge on the sector.

There are many management options that can contribute to better adapted, more sustainable and more climate resilient livestock systems. These include raising the quality of animal diets through improved pasture, feeding higher-quality forage, and diet supplementation with small amounts of concentrates; diversifying breeds and species of the livestock farmed; restoring degraded rangelands and/or improving land-use practices that help to enhance soil carbon sequestration; moving to silvopastoral systems that include trees as a source of feed and shade and to boost soil carbon; managing manure to reduce nitrous oxide emissions from ruminant and monogastric animals, especially in more intensive confined production systems; and using weather information and weather-based insurance products. Most options have constraints to their uptake, such as lack of access to technology, substantial upfront costs and/or benefits that are deferred to subsequent seasons, lack of knowhow, lack of skilled labour, and insecure land tenure. Many of these constraints can be addressed with policy, investment and well targeted research and development initiatives. See Brief 3 (Burkart and Sandoval Yate 2024) for more information on the policies and institutions needed to transform livestock systems under climate change.

Where appropriate, a move towards fewer but more productive animals will reduce GHG emissions and the land footprint of production. This would have both economic competitiveness and socio-cultural implications in many LMICs. For the former, considerable investment in increasing the efficiency of livestock value chains will be needed, through market and improved service development and increased institutional support, for example. The latter may be tougher to address, as the implications for livelihoods could be profound, though improved profitability and resilience to extreme weather events could help in the longer term.

There are promising prospects for reducing absolute methane emissions from ruminant livestock, including intensified production with fewer animal numbers, managing herd composition, shifting to lower-emission types of livestock, silvopastoralism, grassland restoration, avoided burning of grasslands, and low-emission breed selection. Along the supply chain, more efficient and renewable energy in the cold chain is a major option for mitigation. While additional measures such as feed additives (Hegerty et al. 2021), manure management or alternative proteins also can reduce methane, these technologies are not yet available, affordable or relevant to many lower-income farmers. Vaccination against methane production (still in early trials), and direct modification of the rumen microbiome are areas of current research. The feasibility, sustainability and animal production co-benefits or side effects of such interventions are work in progress. The uptake at scale of any such interventions could lead to perverse incentives that increase consumption of animal source food (ASF) and hinder the livestock sector reducing reduced emissions.

Changes in the make-up of ASF demand could have considerable environmental as well as human health benefits in some societies. For example, substitution of monogastric meat for ruminant is already well underway in some countries, and rapid urbanization and shifts to fast foods may drive further monogastric demand. Similarly, if substitution of alternative protein for ASF becomes widespread, environmental and health benefits could be large, though at a cost of considerable value chain disruption.

Prioritizing climate action in the livestock sector may not be straightforward: the agricultural areas with most of the emissions, and those with significant climate hazards, are not always the same. Action that prioritizes adaptation and mitigation separately may be needed in such areas. Where emissions and climate hazards do overlap, actions that address mitigation and adaptation at the same time would increase the effectiveness of scarce resources. For impact at scale, a focus on adaptation and mitigation actions in the agricultural landscapes where they are most needed may be most effective. Particularly in small-scale systems, the value of livestock to livelihoods goes far beyond their productive capacity. Balancing these considerations is essential in prioritizing effective climate finance allocation and equitable climate action outcomes at local scales.

Goat in Inhambane province – Mozambique (photo credit: ILRI/Saskia Hendrickx).

Although the focus may shift in different contexts, the overarching need to reduce emissions from the livestock sector while meeting future demand for ASF and sustaining livestock-based livelihoods is critical. Livestock farming is often located in vast frontier and fragile areas, where there are substantial challenges for outreach and achieving impact with respect to both adaptation and mitigation actions. At the same time, the livestock sector is growing rapidly, creating opportunities for a sustainability transition. The following sections consider future ASF demand and consumption trends, data gaps, projected climate impacts on livestock systems, and the effects of livestock on climate, from an adaptation-mitigation perspective, as well as the substantial uncertainties involved. We then outline the roles played by improved governance, adequate climate finance and technological innovation, in the planning, implementation and monitoring of integrated livestock development that can satisfy demand, achieve emission targets, and enhance the well-being of all stakeholders in the sector.

2. Livestock demand and consumption trends

The evolution of the global livestock sector over the last 30 years can be summarised in three strands, from Herrero et al. (2023). First, demand for poultry has been the main global driver of increased meat consumption, with a near doubling of per capita consumption since 1990. Second, per capita dairy consumption in higher-income regions has stayed constant since 1990, production growth being driven by population growth. Lower-income regions have seen significant increases in dairy consumption, driven by both population growth and increased per capita consumption. Third, increases in global beef demand is largely down to China and Brazil, which account for nearly 93% of the 11 Mt increase in global beef demand. Historically, shifts to beef consumption have occurred as incomes rise. Other than China and Brazil, beef consumption in LMICs has not increased appreciably, and in many HICs, it is declining; white meats are often cheaper than red, and health and environmental messaging may be having an increasing influence on consumer behaviour.

Livestock production has grown rapidly in response to increasing demand. The last 35 years have seen an increase of about 35% in global per capita demand for meat, mostly poultry and pork. Demand for dairy products continues to grow in most regions. The increase in consumption of ASF in some countries has outstripped supply, leading to substantial increases in international trade in animal source foods. Although the value of exports has quintupled since 1990 to more than USD 300 billion, this is less than 20% of global production. In terms of volume, trade in livestock products is less than 10% of the trade in animal feed, which is likely to intensify to satisfy growing demand for pork and poultry in importing regions.

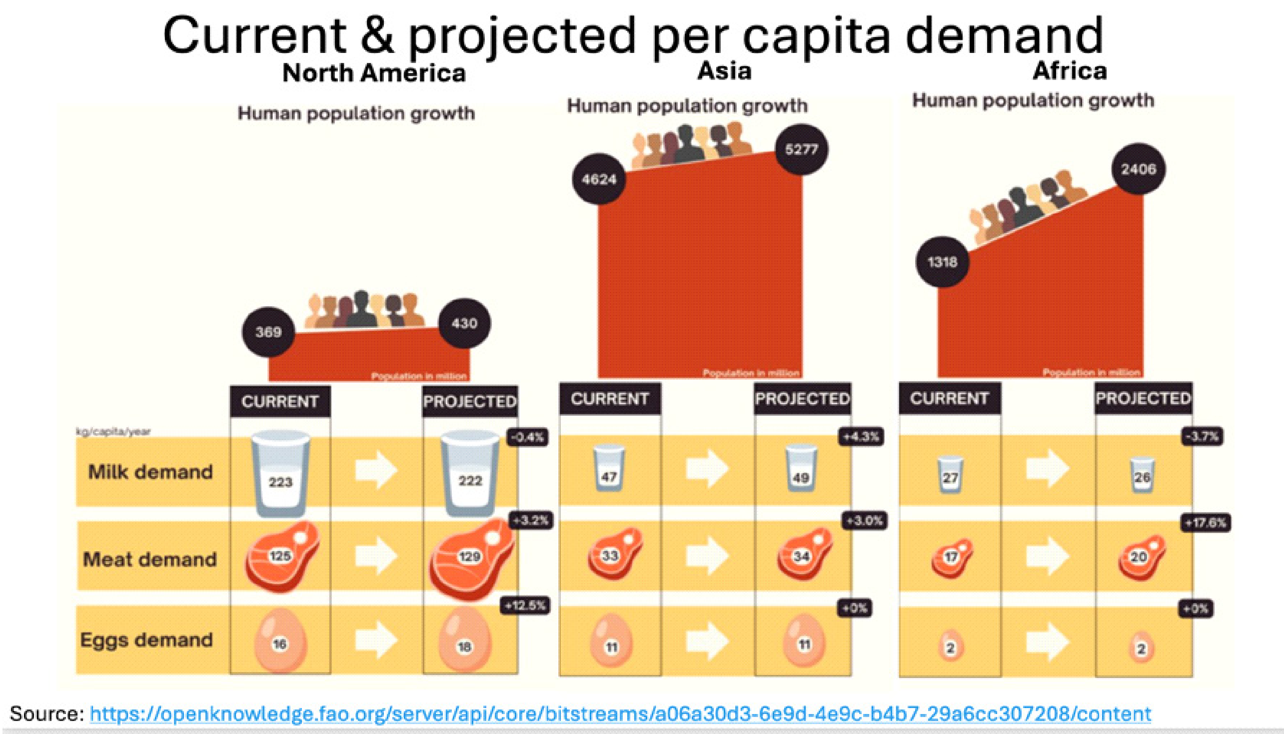


Figure 2: Trends in per capita demand for milk, meat and eggs in three regions.

ASF is produced across most of the major agroecological zones of the world with a widely differing levels of intensification and resource use efficiencies. In general, livestock numbers closely track demand trajectories. Since 1990, the global tonnage of meat, milk and eggs produced has increased by just under 2% per year, with particularly high production increases in Africa and Asia. In higher-income regions, production has grown at a slower rate, and in Europe it has declined by more than 16% since 1990.

Production efficiency gains in some regions have been associated with intensification, sometimes leading to a reduction in animal numbers. But productivity in sub-Saharan Africa has remained essentially stagnant, with production increases fueled by increasing animal numbers; an exception is highland production systems of countries such as Kenya and Ethiopia, where increases in dairy productivity have outstripped the growth in animal numbers.

These trends seem likely to persist, although the extent to which they will modify the livestock sector in the coming decades is highly uncertain. The effects of dietary changes in response to environmental, socio-economic and cultural concerns, as well as those related to human health and nutrition, coupled with a growing market for alternative proteins for food and feed, could be profound and highly disruptive to existing ASF livestock chains.

The future role of small-scale livestock production, which provides livelihoods for at least 650 million people in LMICs, is likewise highly uncertain. A sustainably intensified smallholder dairy sector could help drive future production growth in places where there are still large yield gaps and demand is growing. Elsewhere, land fragmentation and feed scarcity may decrease the viability of the sector. Small-scale production of beef, dairy, pigs and poultry will continue to be crucial for local food security in many places, but as economies grow, smallholder production may decline in economic importance as conditions become more conducive to the industrialisation of these sectors.

Climate change may modify these trends in several ways. The places where climate change impacts are likely to be the greatest are also the places where demand is growing the most. The more capital-intensive livestock production systems will generally fare better than the smaller-scale, less intensive production systems, because of a greater ability to implement adaptation and mitigation measures. The livestock farmers who are already vulnerable will become even more so. At the same time, livestock farmers will face increasing uncertainty in the production and marketing of ASF. These factors underscore the need for investment in diversification and risk management, alternatives for a just transition for smallholders, and highly innovative research and development action.

3. Climate projections and impacts on livestock

Climate change is already having substantial effects on livestock systems, and these impacts will become more pronounced. Despite gaps in knowledge of the impacts of climate change on livestock, there is little good news: to mid-century, many of the impacts are already baked in, highlighting the importance and urgency of both mitigating emissions as rapidly as possible and enabling vulnerable people throughout the livestock value chain to adapt to increase their resilience (Godde et al., 2021; Kerr et al., 2022).

Grassland productivity is projected to be seriously affected to mid-century, though there are regional differences in the impacts. Changes to African grassland productivity will have substantial, negative impacts on the livelihoods of >180 million people, though the future makeup of grasslands in general under climate change is uncertain. Grassland composition changes will inevitably modify their suitability for different grazing animal species, with switches from herbaceous grazers such as cattle to goats and camels to take advantage of increases in shrubland. Crop residue production changes will mirror crop production changes, though as for pasture, quality will also be affected, as warming, water deficits and increased CO_2 concentrations may impair digestibility and nitrogen content of forage.

Direct and indirect processes link climate change and infectious diseases in livestock. Some like Bluetongue virus show a positive association between temperature changes and expansion of the geographical ranges of arthropod vectors, while others like tsetse flies show a contraction. Positive associations with extreme weather events exist: increased risk of flooding and future Rift Valley Fever outbreaks are projected in East Africa this century. In general, though, the impacts of climate change on livestock diseases remain highly uncertain.

Water resources for livestock may decrease because of increased runoff, greater plant evapotranspiration, and reduced groundwater resources. Changes in river flow and the amount of water stored in basins will exacerbate water stress for both humans and livestock, especially in dry areas. Changes in availability will likely be accompanied by changes in water quality, such as increased levels of microorganisms and algae, compromising reproductive performance and productivity in domesticated animals. Although water consumption by livestock is only 1-2% of global water consumption, warming will increase animals' needs. Increased frequency and intensity of droughts and floods will severely affect herd stability and increase restocking time.

Direct impacts of heat stress on animal health and production will become increasingly serious. Animals eat 3–5% less per additional degree of temperature, reducing productivity, affecting fertility, and increasing disease susceptibility. Goats cope better with heat stress than sheep, and both species are more heat resistant than cattle. To mid-century, land suitability for all domesticated livestock production, particularly cattle, will decrease because of increased heat stress prevalence in mid and lower latitudes. The costs of cooling in intensive production systems will inevitably rise. There is limited information on the impacts of heat stress on backyard pig and poultry production.

Increasing heat stress will also negatively affect human labour capacity. Labour availability and productivity are key determinants of the efficiency of the livestock supply chain, especially in LMICs with limited mechanization. Human labour capacity is projected to decline by up to 20% by mid-century in the low latitudes of Asia and Africa because of rising heat stress, which also affects several communicable diseases and further impact the health of people working in the open air. Increasing risk of zoonoses is expected for populations in close contact with livestock and wildlife, with increasing frequency and severity of extreme events contributing to seasonal or permanent displacement of rural populations and effects on labour supply.

Biodiversity, which underlies all the goods and services provided by ecosystems that are crucial for human survival and well-being, is affected by many climate hazards. Many of these have negative impacts on resilience in small-scale farming systems, which may be compounded by increased competition for other land uses. When well-managed, however, livestock production can help improve the biodiversity of grass and tree species and the soil, especially in rangelands where it is difficult to produce other types of food (AU-IBAR, ILRI and GIZ, 2024). More information on the linkages between environmental health, climate change and livestock production is available in Brief 4 (Frija et al. 2024).

There are many ways in which livestock farmers can adapt. These include changing their animals to more stress-tolerant breeds or species, modifying the way in which they manage feed, labour and water resources, varying the location of their operations where possible, and even switching their products and product markets, possibly including a move away from livestock farming to other livelihood activities. Traditional crop and livestock farming in the lower latitudes of many LMICs will face rising challenges in the coming decades, and considerable innovation will be needed throughout the livestock value chain to address them. Some of the innovations needed are already being pioneered by livestock keepers themselves, and scaling out such locally led solutions can be encouraged by extension systems. More information on how this can be done is contained in Brief 2 (Habermann and Crane 2024). However, there will increasingly be situations where available adaptations will not be sufficient. Improved understanding of the limits to adaptation will be critical for targeting alternative livelihood strategies for the most vulnerable populations, and these may well involve exiting agriculture (Thornton et al., 2024).

4. Reducing livestock's impact on climate

Livestock is the single largest driver of emissions in the land sector, contributing about 60 percent of emissions. Mitigation is therefore a priority to meet Paris Agreement targets. Livestock is the top driver of land use emissions in every region of the world: Africa and Middle East (89% of land sector emissions), Latin America (81%), Eastern Europe and West Central Asia (57%), high-income countries (49%), and Asia and developing Pacific (32%) (Roe, 2021). Livestock emissions are likely to grow by ~17% by 2050 (FAOSTAT 2024). Without addressing livestock emissions, it will be difficult to meet global climate policy targets.

Yet most countries lack domestic policy for tackling absolute reductions for methane from enteric fermentation, the major source of emissions from domesticated animals. Livestock is a major source globally of methane, which has a global warming potential 28 times that of carbon dioxide. Ruminants' digestive systems alone contribute 27% of global anthropogenic methane (Arndt et al. 2022). Methane is also a gas that breaks down quickly in the atmosphere (Costa et al. 2021), so reducing methane emissions can also quickly have an impact on the balance of methane in the atmosphere and global warming. Methane emissions from ruminants must decrease by 24% to 47% by 2050 to meet the 1.5 °C target (Arndt et al. 2022b).

Many countries have existing policies and programs to improve animal productivity, which can decrease emission intensity, or methane-efficiency per unit of livestock product. Improvements in emission intensity are a good low-emission development strategy that enable producing food with higher GHG-efficiency. However, if animal numbers also increase, absolute emissions will increase and worsen climate change. The challenge for the livestock sector is to develop technologies accessible and affordable in the Global South that can help reduce methane in absolute terms, and enable the policies, finance and technical support to implement these technologies at large scales.

It is time to move from global pledges and national targets to local action at scale. While about 100 countries have committed to livestock-related mitigation or adaptation measures in their nationally determined contributions (NDCs) to the Paris Agreement, with ~65 countries committing to livestock measures in the first round of NDCs (Richards 2019) and ~35 additional countries in the second round (Dittmer et al. 2024, Rose et al., 2022), countries now need to increase ambition; provide quantified targets, reference levels of indicators and mitigation potentials, and most importantly develop realistic measures for implementation.

As of October 2024, only 68 countries had provided new or updated NDCs that included livestock measures (Figure 3) (Dittmer et al. 2024). These included 7 of the top 10 emitters of livestock emissions; India, Australia and Spain had yet to make commitments (Rose et al., 2022). Common measures for mitigation were manure management (22% of countries), feed management (17%) and silvopastoralism (11%). For adaptation, common measures were breed management (18%), silvopastoralism (10%) and feed management (10%). Few countries set mitigation targets related to the NDCs. Only 12 included targets consistent with the Global Methane Pledge of reducing methane 30% by 2030 (Dittmer et al. 2024). See Annex 1 for more examples of adaptation and mitigation measures in the NDCs.

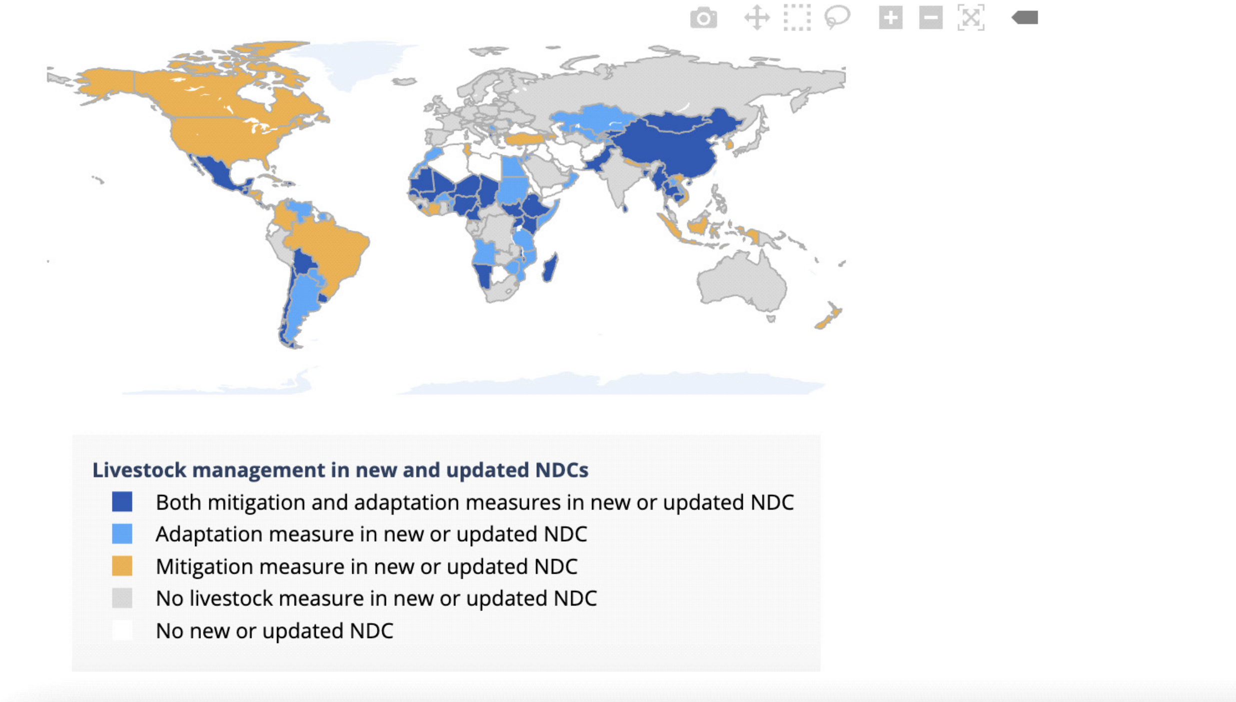


Figure 3: Livestock management in the new and updated NDCs
Source: Dittmer et al. 2024.

Absolute net emissions reductions are possible and necessary at large scales to make a difference for the climate. While at least 35 measures have been shown to reduce methane emissions, reductions vary from 5 to 43 percent and some measures reduce only product-based emissions (Arndt 2022b). Product-based strategies for reducing emissions such as improved feed and increased feed intake are important—reducing emissions by 9 to 17 percent per product--but need to be combined with absolute measures to affect climate change. Measures for absolute reductions include reducing animal numbers through more intensive production, shifting to different kinds of animals with lower emissions (e.g. low-emissions cattle, chicken), or using products such as methane inhibitors, tanniferous forages, electron sinks, oils and fats, and oilseeds in the diet. Such products can decrease daily methane by 12 to 32 percent, or on average 21 percent (Arndt, 2022b, Hegarty et al., 2021). Using multiple measures will be needed to achieve targets. Use of renewable and efficient energy in the supply chain can be an important mitigation option, especially in dairy systems.

The livestock sector also has a tremendous opportunity to offset emissions through carbon sequestration in pasture soil and biomass, including rotational grazing, optimizing grazing intensity, sowing legumes and restoring grassland cover and biodiversity. Grassland management can increase soil carbon stocks by about one half a ton of carbon per hectare per year, contributing to as much as 10.2 billion tons CO2e per year, although only one-third of that is realistically achievable (Bai and Cotrufo 2023). Grassland restoration has a high potential for impact at large scales (Box 1). Avoided burning of grasslands or crop residues will also maintain carbon.

Box 2: Grassland restoration for carbon sequestration at large scales

The Northern Kenya Grassland Carbon Project, established by the Northern Rangeland Trust in 2015, works with 16 thousand pastoralists on 2 Mha, where they will reduce emissions by 1.67 Mt CO_2e/yr over 30 years.

Carbon developer Boomitra is promoting rotational grazing of beef cattle and water conservation measures for biodiversity on private and communal lands in Northern Mexico. Established in 2018, their project works with 30 thousand smallholder farmers on 800,000 ha, where they expect to reduce emissions by 7.3 Mt CO_2e/yr over 20 years.

Mitigation strategies need to be tailored to country conditions. In low-income countries, for example, improving feed should focus on human inedible feeds (i.e., forage and by-products) to reduce competition with food production (Arndt, 2022b). More details on improving feeds and forages for both mitigation and adaptation are provided in Brief 6 (Cardoso, et al. 2024). Growth in the human population is expected to be the largest driver of future livestock consumption, in addition to somewhat increased consumption per person and by 2050 will overtake planned mitigation to date, suggesting that stronger measures will be needed. In countries with overconsumption of meat, mitigation strategies should include reducing meat consumption and food waste (Rust et al., 2020). These measures may include changing dietary norms, marketing, improving consumer awareness and developing new products.

Winner of goat show weight competition weighing 179kg
National goat show at Faisalabad, Pakistan 19-21 Oct 2012 (photo credit: ILRI/M Sajjad Khan).

5. Conflict, migration and governance trends in livestock production areas

Livestock production occurs in some of the world's most politically fragile regions due to conflict, migration and weak governance. Fragile areas include the Somali Peninsula, Central America and the Middle East. For example, armed conflict is common in the pastoral areas of the Middle East and Somalia, South Sudan, and parts of the Sahel. Eight percent of farming households in Central America's Dry Corridor considered migration in 2019, driven by extreme weather events like prolonged drought (Pons 2021). The resulting instability and poverty exacerbate farmers' and herders' vulnerability to climate change. Countries lack the resources needed to support farmers to mitigate emissions. Women are disproportionally disadvantaged by loss of livelihood or displacement and often the primary managers of small animals such as sheep, goats or chickens, yet their knowledge for adaptation is often overlooked. These areas are often served by humanitarian assistance rather than development assistance for climate change adaptation and mitigation. Yet they cannot be overlooked.

Political insecurity can disrupt supply chains and displace communities, resulting in decreased livestock assets. The Syrian civil war led to USD 5.5 billion in costs due to loss and damage in the livestock sector and 60 percent of households reported selling off livestock assets (FAO 2017). Similarly, 12 percent of households in Burundi reduced livestock numbers due to political instability and insecurity and the need to sell off assets (FAO and WFP 2016). Migration causes loss of assets as well. Livestock holdings declined from 42 to 2 livestock units among 17.5 million internally displaced persons (IDPs) of the Greater Horn of Africa region (mainly Ethiopia, Sudan, Somalia, and South Sudan) (Joint Data Center on Forced Displacement 2024).

Conflict zones often have damaged infrastructure and reduced capacity to deliver livestock feed and veterinary services, resulting in threats to livestock health and productivity. War in Yemen led to damaged veterinary facilities, with subsequent outbreaks of animal disease (FAO 2024). Trade and access to markets can also be compromised. Post-conflict recovery in livestock production areas require significant resources to rebuild livestock-related infrastructure and restore inputs and veterinary services to stabilize livestock production and support livestock farmers. More information on the nexus between climate, conflict and security within livestock systems can be found in Brief 1 (Synnestvedt, Maviza and Pacillo 2024).

Effective governance can support better infrastructure, services, and regulations which can in turn increase agricultural productivity, including for livestock. Effective governance can enable farmer innovation for new climate change adaptation and mitigation practices and provide farmers with the access to land, livestock breeds, finance, markets, technologies veterinary services and infrastructure that they need. It can also regulate, set livestock targets and assign finance needs in its national climate change strategy and NDCs. However, weak governance can undermine these efforts, leading to weak implementation and conflict. There is a need for integrated risk management, including water, energy and food for the livestock sector and within jurisdictions and ecosystems (IPCC, 2022).

The overlap between livestock production areas and zones of political fragility and conflict highlights the need for integrated approaches to managing risk through humanitarian assistance linked with early warning systems and climate information systems for livestock systems. Effective humanitarian services and sustainable recovery strategies are essential to ensure the resilience of the livestock sector and the well-being of affected communities.

6. Climate finance for livestock

Climate finance for livestock amounts to a small fraction of what is needed. Less than 10% of the climate finance for agriculture of USD 28.5 billion per year, including USD 5.5 billion per year to smallholders (Chiriac et al., 2020, Chiriac et al., 2023), is estimated to go to livestock according to major donors in the livestock sector. Investors generally view the livestock sector as risky, with low profitability, high environmental impacts that are difficult to monitor, and lacking in centralized entities that can be responsibly financed. Smallholder livestock farmers also often live in remote or unstable regions, with poor access to credit (Gerber et al., 2021). Few livestock enterprises are "investment ready," further dissuading investment. The European Union's animal welfare requirement is a restriction that discourages many investors.

Major agriculture and climate change donors (ADB, BMZ, USAID, BMGF, and the Green Climate Fund) typically have had fewer than two livestock projects in their climate program, making up less than 10% of finance available. Livestock has often been embedded in larger agriculture projects aiming to improve production efficiency, animal nutrition and sustainably sourced feeds, manure management, energy-efficiency, renewable energy, and animal health and welfare. Common climate specific investments have been livestock insurance and carbon sequestration, as well as climate-smart agriculture practices for feed and livestock production. Dairy investments included energy efficiency. Donors have recognized the need for more investment in climate change aspects of livestock production.

Private sector investment for livestock is primarily channeled through companies interested in sustainably sourcing meat and dairy rather than livestock producers. Companies include Danone, Saputo, JBS, Marfrig, Minerva, or others further down the supply chain, such as fast-food restaurants, Tyson Foods, Walmart, Maple Leaf Foods. Livestock investors increasingly assess for risks associated with climate change and unsustainability. Agribusiness opportunities related to climate change mitigation and adaptation include improved feed, feed additives, waste management and biogas facilities, more energy efficient cold chains, reduced food loss and waste, intensification of production intensification and avoided deforestation, silvopastoralism and agroforestry with valuable timber or horticultural species, animal housing (heat control, ventilation). Investment in new technologies such as vaccines, additives, and low-emission genetics would also increase financial flows.

Innovative finance can increase the amount of funding flowing to livestock. Innovations include making loans conditional on climate change adaptation and mitigation practices, requiring protection of forests and other high-carbon landscapes as a condition for value-chain finance using product traceability tools; including livestock in national and global emission trading schemes, using overseas development assistance to reward proactive policy, verifying sustainable sourcing of animal feed, and using prize-based programs to drive research and development for innovation (Gerber et al., 2021)

Efforts to reduce enteric methane from livestock are vastly underrepresented in carbon markets. At the same time manure digester projects are prominent, and improved emission monitoring and modeling are supporting an increasing number of large-scale grassland projects. Four hundred and fifty-five projects (~1.3% of all voluntary carbon market (VCM) projects) related to livestock and grasslands are active in the major standards of the VCM globally and of these 125 projects have issued 28.9 $MtCO_2e$ of carbon credits (1.5% of all VCM credits). Only one project using feed additives directly addresses enteric methane and represents less than 1 percent of credits issued related to livestock and grasslands. Methane digester and sustainable grassland management projects have provided the most credits (Table 1)(Haya et al. 2024). Since 2016, sustainable grassland projects have emerged as an important supplier of large volumes of carbon credits, due to new monitoring approaches based on use of remote sensing, modeling and ground-truthed measurements. Only five grassland projects have issued 12.5 $MtCO_2e$. Other project types include avoided grassland conversion, solid waste management and feed additives. Methane projects were also prominent under the Clean Development Mechanism and can be expected to be popular under future United Nations Framework Convention on Climate Change (UNFCCC) Article 6 carbon trading mechanisms.

Voluntary Carbon Project Type	Credits issued (tCO2e	%
Avoided Grassland Conversion	774,612	3%
Feed Additives	3,303	0.01%
Manure Methane Digester	15,176,691	53%
Solid Waste Separation	333,505	1%
Sustainable Grassland Management	12,549,662	44%
Grand Total	**28,837,773**	

Table 1: Voluntary carbon market project types related to livestock and grasslands
Source: Haya et al. 2024

Actions to overcome the challenges to climate finance for livestock include the following:

- Building investor confidence in the livestock sector.
- Reduce risk with due diligence measures, having climate risk assessments for a country and project, develop risk management protocols and share these across development finance institutions.
- Creating more incentives and ease for blended finance.
- Building a pipeline of investment-ready projects to which investors can be directed.
- Estimating the climate finance needed in the sector and potential impacts would help guide investment.
- Supporting program design and technical assistance for climate change adaptation and mitigation, including approaches for achieving net zero targets for mitigation and demonstrating how the activities will support resilience, including examples from diverse countries.
- Mainstream in-house technical capacities for livestock and climate with webinars and publications, and other training.

7. Trends in technology: feed innovation, energy, digitalization

Technology development in the livestock sector, as in many other sectors, is proceeding rapidly. Below we very briefly highlight a selection of promising technologies in three broad domains of innovation: feed innovation, energy, and digitalisation.

Feed innovation. Many **feed additives** have been proposed, and some are commercially available, that enhance some aspects of animal performance. These include betaine, probiotics, chromium, vitamin C and vitamin E. Of the methane-inhibiting feed additives, only two have consistently delivered >20% mitigation of enteric methane: 3-Nitrooxypropanol and red seaweed (*Asparagopsis taxiformis*) (Hegarty et al., 2021). Both are promising and could be utilised in different ruminant production systems. Several ***alternative protein*** sources for animal feed are already commercially available, and others are in the pipeline. These include insects, certain woody plants, and algae. Interest is growing in single-cell proteins made by extracting atmospheric CO_2 and combining it with water, nutrients and vitamins using renewable energy sources. Some alternative proteins may also help ***manage organic waste streams,*** such as those from intensive livestock farming. Microalgae can efficiently recover nitrogen from waste and can be cultivated to produce protein-rich feed for livestock. Insect farming can also help turn waste streams into high-protein livestock feed, feed oil and fertilizer. Uptake may face legislative and consumer-related challenges, and the economic, environmental, and sociocultural benefits and costs that may arise are not completely understood. Nevertheless, the alternative protein subsector is expected to grow rapidly in the next decade or so.

Energy technology. Traditionally, ammonia production is highly energy intensive, and most of the 180 Mt produced annually is used as fertilizer. The fossil fuels used in its production account for nearly 2% of global CO_2 emissions (and its inefficient application and use account for another 2%). ***Green ammonia,*** produced using renewable energy, has considerable potential as a carbon-free fuel and fertilizer. It can be produced at small scale, and should provide cheap, timely and locally available N fertilizer, helping to increase grassland productivity as well as raise crop yields. Pilot plants are already being set up in East and southern Africa. As the efficiency of solar panels increases and their cost declines, ***solar farming*** may become feasible in many LMICs, particularly in more remote rural areas where the electricity grid is weak or non-existent. Although chemical batteries dominate the current energy storage market, there are new technologies for thermal storage that offer great potential for storing renewable energy to be used when needed on-farm, to power micro-irrigation pumps and small evaporative cooling units for storing milk, fruit and vegetables, for example. One option for the future is ***agrivoltaics,*** which combine solar panels for energy capture with crop and livestock production. With shade-tolerant species, such systems may increase household income substantially, as well as help reduce the impacts of heat stress in livestock grazing under the panels.

Cows walk along an irrigation canal in Niolo, Mali (photo credit: ILRI/Stevie Mann)

Digitalisation. Farm-to-fork virtual marketplaces offer small-scale producers the opportunity to become connected with different food purchasers using online- or smartphone-based platforms that link suppliers with end-users directly. Benefits include more efficient and timely supply chains, increased producer profits, decreased food loss and waste, and increased traceability of food production. There are already several functioning farm-to-fork virtual marketplaces in LMICs, and the subsector is likely to expand in emerging markets where populations are urbanizing and incomes rising.

Virtual fencing consists of fitting animals with collars containing GPS devices with the coordinates of their grazing areas. If animals move out of their designated grazing areas, they receive a negative stimulus – an audio tone and/or electric pulse - and through training, cattle rapidly learn to keep within their designated areas. Benefits include improved grassland management and pasture restoration, and reduced costs by alleviating the need for fencing and labour to manage herd movement.

Data collection and analysis methods are changing rapidly via many new and developing technologies that can increase the temporal and spatial scale of data. These include high-resolution and high-frequency satellite remote sensing data, use of drones, citizen science and crowdsourcing. Survey data collection in remote areas is becoming easier with smartphone-based, open-source platforms; and example is KAZNET, being used in the pastoral regions of East Africa (Chelanga et al., 2022). Several non-invasive methods are now available to measure methane production in ruminants, including microbial biomarkers in the rumen, hand-held methane sensors, and ingestible methane monitoring capsules. Novel sensor technologies (the Internet of Things) make it possible to automatically manage animal feeding and disease control at the individual level (precision livestock farming). The rapidly developing methods of artificial intelligence and machine learning may radically change the ways in which data are collected and analysed. In time, ***robotics*** may be able to help address the labour shortages that are common in agriculture throughout the world, allowing labour-intensive and repetitive tasks to be carried out automatically. Their role in small-scale production systems in LMICs is yet to be determined.

8. Research needs and data gaps

Over the past decades livestock R&D in lower-income countries has been seriously hampered by underinvestment in data collection, curation and dissemination. The lack of up-to-date, timely and salient information is a serious impediment to the prioritization of investment options and policy formulation and implementation in the livestock sector, and to the monitoring of livestock, livelihood and environmental performance.

The major domesticated livestock species are distributed across all the major agroecological zones of the world in a bewildering array of production system, intensification level and resource use efficiency. In 2022, there were estimated to be 42 million camels, 205 million buffalo, 1.0 billion pigs, 1.1 billion goats, 1.3 billion sheep, 1.6 billion cattle, and 26.6 billion chickens (FAOSTAT, 2024). There are few areas of the globe between latitudes 60°S and 60°N that are completely bereft of at least one of the "big five" species (cattle, sheep, goats, pigs, poultry). Many other species are domesticated in some regions, including donkeys, ducks, alpacas, llamas, horses, rabbits and yaks. Estimates of the number of different breeds vary, but more than 5000 breeds of the big five have been described.

The current state of global livestock and climate data is moderate at best. Data on livestock numbers and production levels are available at country level in FAOSTAT, collated from a wide range of sources such as national censuses, surveys and estimation procedures. These data allow comparisons across and between all countries and regions, and annual time series are provided going back to 1961 for most variables. The Gridded Livestock of the World (GLW; Gilbert et al., 2018) dataset contains spatially modelled population numbers for 2010 (soon 2020) for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks, harmonised to match national level FAOSTAT data. Two other global data products are FAO's Global Livestock Production Systems (Robinson et al., 2011) and the Herrero et al. (2013) dataset on livestock biomass use, production, feed efficiencies and greenhouse gas emissions; the latter is being updated to the year 2020.

There are several regional and global livestock and climate data repositories at different scales, and these need to be expanded. These include the global rangelands atlas (https://www.rangelandsdata.org/atlas/), the sub-Saharan Africa adaptation atlas (https://adaptationatlas.cgiar.org), and the Livestock Data for Decisions repository (https://livestockdata.org/). An Atlas of Climate Adaptation in South Asian Agriculture (https://www.cimmyt.org/projects/atlas-of-climate-adaptation-in-south-asian-agriculture-acasa/) is under development. Such tools provide data and case studies on a range of different livestock-related topics. The collation of different use cases by policy makers, scientists, development agencies and funders should help to ensure the sustainability and maximise the utility of such initiatives. Interactive climate atlases such as those developed by the IPCC make state-of-the-art climate data readily available, though such data often need reformatting and/or reanalysis to be of use to scientists and decision makers.

There are many datasets at sub-national level, but these often have limited coverage, a big constraint for comparative studies. Several sources of household survey data provide some comparative information on livestock. These include the World Bank's Living Standards Measurement Studies (LSMS) and the Rural Household Multi-Indicator Surveys (RHoMIS). Both contain livestock modules, and LSMS data cover more than 40 countries and RHoMIS contains data for some 54,000 households in 36 countries. These are good sources of livestock information, suitable for studies where complete coverage is not required.

Critical livestock and climate data gaps persist, particularly in LMICs. Ruminant diets are often made up of a wide range of feed resources, such as natural and planted grassland of different types, crop residues, grain- based and other supplements, and cut-and-carry fodders. RHoMIS and other household survey data are invaluable in understanding livestock diets in different situations, but incomplete coverage remains a barrier to many types of analysis. Another gap concerns the number and distribution of different animal breeds. Dairy and dual-purpose (milk-meat) production generally has to be inferred from other data, and we still lack detailed distribution datasets of even broad classes of livestock such as cattle. Some emission factors are available for smallholder systems, but more work is needed and activity data are often lacking or poor quality. Such gaps as these make it challenging to prioritise adaptation and mitigation options and quantify the costs and benefits of different actions. In view of data gaps and major uncertainties concerning future evolution of the climate system and the livestock sector, the role of scenario analysis in guiding future livestock development may become increasingly important. Participatory visioning and scenario building processes have developed considerably in the past few years and are being used at scales ranging from the local to the national and beyond (Pereira et al., 2020; Rutting et al., 2021).

Several challenges affect livestock and climate data. Defining the nature and extent of grazing systems and the complexity of associated land cover (pasture, browse, bare land, all gradations in between) presents considerable difficulties. In many LMICs, mixed systems predominate, in which crops and livestock occupy the same or adjacent areas; moreover, 70% of farms globally are <1 ha in size, which further complicates characterization of small-field mixed systems. In rangeland systems, where animal movement is a crucial management tool, transboundary risks of animal diseases that may have devastating impacts is a further complication, as neighbouring countries may not have comparable data collection initiatives on animal health and cattle movements.

To increase the coverage and scope of information on livestock systems and production, substantial investments will be needed. The tools and methods of data collection are changing rapidly: digitalisation, citizen science and social media platforms, novel sensor technology, and artificial intelligence, for example. While there are many opportunities for more accurate, affordable and timely data collection, the challenges of data governance need urgent resolution. Major research and development funders could play a key role in promoting standardized data collection, documentation and accessibility procedures, by making them a requirement for funding.

Investment is also needed in data for climate information services and early warning systems for livestock farmers. As the frequency and impact of extreme climate events increase because of climate change, the role of climate information services and early warning systems could expand substantially, to help farmers dampen seasonal and annual fluctuations in productivity and income. With appropriate interventions, these tools could also help shorten the time required to rebuild herd and flock numbers after devastating drought and flood. Investment in farmer training and provision of timely and salient extension information would also be needed.

9. Summary and conclusions

Policy makers can provide incentives to farmers, bundled with technology and finance, to support implementation at scale. Incentives can be created through consumer awareness and demand (e.g. labeling), market premiums, more attractive finance options, policy compliance or tax concessions, carbon markets, impact investment, subsidies, payments for ecosystems services, regulation, farmer capacity strengthening. Incentives for R&D on improved mitigation technologies is necessary to achieve higher levels of mitigation. Policy makers can also support improved statistics for livestock, including Tier 2 measurement.

Policy makers and investors in livestock can do their part by integrating low-emissions development strategies into livestock investments, supporting information systems to monitor the impacts of livestock investments, and supporting technical innovations. Agricultural investments that increase livestock numbers without also reducing emissions will exacerbate climate change. Analysis of such trade-offs is necessary for responsible donor investment. Investment is needed especially in creating incentive mechanisms and supporting farmer-facing groups to provide technical assistance and finance to farmers. At country and regional scales, enhanced public data platforms, modelling and capacities for measurement and monitoring of Tier 2 methods will improve estimate emissions and reductions (Gurmu et al. 2024).

Policy responses concerning the climate-livestock-livelihood nexus need to be carefully tailored to both local and regional contexts. A wide range of response pathways will be needed for different situations, and many of these will need to address cross-sectoral issues: humanitarian assistance, human nutrition and health, sustainable intensification, industrialisation, water supply, energy, infrastructure, non-agricultural activities, gender equity and social inclusion to name several. Ensuring that women, youth and other marginalized groups are involved in livestock and climate policy responses will be critical (see Brief 5 (Bullock, Dutta Gupta and Triana-Agnel 2024) for more on this). Despite many uncertainties, the livestock sector in 2045 will likely be considerably more fragmented and diverse than it is today. Monitoring the outcomes and impacts of change will form an increasingly crucial component of the livestock development agenda in future.

A huge need is to support livestock-specific frameworks and data and information systems for monitoring impacts. Frameworks were aligned loosely with the Paris Alignment and Sustainable Development Goals, using organization appropriate indicators and safeguards concepts. New indicators are being developed to specifically monitor methane and mitigation practices and science-based targets for livestock or methane. There is a need for simple, small sets of science-based indicators for resilience, adaptation and mitigation, as well as checklist for investment specialists on GHG protocol requirements for livestock. The principle of “do no harm” to achieving net zero is used by the multilateral development banks, which is challenging to assess based on assessment of best practices. Country-driven institutions with diverse programs make it difficult to have hard commitments to targets. For example, three of four East African countries in GCF’s new livestock project have not joined the Global Methane Pledge. The evidence base for evaluating impacts was usually standard project-level evaluation, with little portfolio analysis. More robust ex-post assessment is needed with models and data specific to production systems and integrated systems.

Time's up: future investment in livestock must take on a new trajectory to yield successful climate change outcomes. Development of the livestock sector has focused conventionally on economic factors such as productivity, finance and livelihoods, but the challenge now is how to integrate environmental, nutritional and social dimensions. This document has outlined several opportunities for modifying the trajectory of livestock development in the face of climate change. In broad terms, these revolve around the following:

- Building on the considerable store of what we do know about livestock and climate change and bundling new methods and technology with old, to create innovative responses to the challenges that assail livestock systems and the people who operate and depend on them.
- Where there are persistent data and information gaps, aligning new investments to help fill these, enabling better-informed decisions to be made.
- Because the future is highly uncertain, fostering anticipatory and responsible governance at local, landscape and national levels, via participatory, multi-stakeholder processes and coalitions of the willing, in the search for sustainable and equitable livestock development.

References

Arndt, C., Hristov, A. and Dijkstra, J. 2022a. Less burping, more meat and milk: how livestock farmers can help tackle the climate crisis. (Available from https://theconversation.com/less-burping-more-meat-and-milk-how-livestock-farmers-can-help-tackle-the-climate-crisis-194822) (Accessed 15 January 2025)

Arndt, C., Hristov, A.N., Price, W.J., McClelland, S.C., Pelaez, A.M., Cueva, S.F., Oh, J., Dijkstra, J., Bannink, A., Bayat, A.R., Crompton, L.A., Eugène, M.A., Enahoro, D., Kebreab, E., Kreuzer, M., McGee, M., Martin, C., Newbold, C.J., Reynolds, C.K., Schwarm, A., Shingfield, K.J., Veneman, J.B., Yáñez-Ruiz, D.R. and Yu, Z. 2022b. Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 °C target by 2030 but not 2050. Proceedings of the National Academy of Sciences 119(20): e2111294119. doi: 10.1073/pnas.2111294119

AU-IBAR (African Union Inter-African Bureau for Animal Resources), ILRI (International Livestock Research Institute) and GIZ. 2024. Introduction to a new narrative for livestock and biodiversity: Livestock must be part of the solution to sustainably managing Earth's biodiversity. Nairobi, Kenya: ILRI.

Bai, Y. and Cotrufo, M.F. 2022. Grassland soil carbon sequestration: Current understanding, challenges, and solutions. Science 377: 603-608. doi: 10.1126/science.abo2380

Bullock, R., Dutta Gupta, T. and Triana-Angel, N. 2024. Socially inclusive and equitable approaches for resilient livestock systems. Livestock and Climate Outlook Series Brief 5. Nairobi, Kenya: International Livestock Research Institute and Alliance of Bioversity and CIAT.

Burkart, S. and Sandoval Yate, D.F. 2024. Policy and institutions needed to transform livestock systems under climate change. Livestock and Climate Outlook Series Brief 3. Nairobi, Kenya: Alliance of Bioversity and CIAT.

Cardoso, J.A. 2024. Improved forages for increased livestock productivity and climate adaptation and mitigation. Livestock and Climate Outlook Series Brief 6. Nairobi, Kenya: Alliance of Bioversity and CIAT.

Chelanga, P., et al. 2022. KAZNET: An open-source, micro-tasking platform for remote locations. Frontiers in Sustainable Food Systems 6: 730836.

Chiriac, D., Naran, B. and Falconer, A. 2020. Examining the climate finance gap for small-scale agriculture. Climate Policy Initiative. (Available from https://www.climatepolicyinitiative.org/wp-content/uploads/2020/11/Examining-the-Climate-Finance-Gap-in-Small-Scale-Agriculture.pdf) (Accessed 15 January 2025)

Chiriac, D., Vishnumolakala, H. and Rosane, P. 2023. Landscape of climate finance for agrifood systems. Climate Policy Initiative. (Available from https://www.climatepolicyinitiative.org/wp-content/uploads/2023/07/landscape-of-climate-finance-for-agrifood-systems.pdf) (Accessed 15 January 2025)

Costa Jr, C., Wironen, M., Racette, K. and Wollenberg, E. 2021. Global Warming Potential* (GWP*): Understanding the implications for mitigating methane emissions in agriculture. CCAFS Info Note. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Dittmer, K.M., Rose, S.C., Khatri-Chhetri, A., Stier, M., Trang, V.H. and Nelson, K. 2024. Agricultural sub-sectors in new and updated NDCs: 2020-2024. doi: 10.7910/DVN/4PO5Z0

FAO (Food and Agriculture Organization of the United Nations). 2017. Counting the cost agriculture in Syria after six years of crisis. Rome, Italy: FAO. (Available from https://openknowledge.fao.org/server/api/core/bitstreams/b9c4f6d8-4fb8-42bb-a2c9-e018e38b1167/content) (Accessed 15 January 2025)

FAO (Food and Agriculture Organization of the United Nations). 2024. Fighting animal diseases in Yemen. FAO Newsroom. Rome, Italy: FAO. (Available from https://www.fao.org/newsroom/story/fighting-animal-diseases-in-yemen/en) (Accessed 29 December 2024)

FAO and WFP (Food and Agriculture Organization of the United Nations and World Food Programme). 2016. Monitoring food security in countries with conflict situations. Rome, Italy: FAO/WFP.

FAOSTAT. 2024. FAO statistical database. Rome, Italy: FAO. (Available from https://www.fao.org/faostat/en/#data) (Accessed 15 January 2025)

Frija, A., Notenbaert, N., Yogezu, Y.A., Alary, V. and Mannai, A. 2024. Reducing the environmental footprint of livestock production. Livestock and Climate Outlook Series Brief 4. Nairobi, Kenya: International Center for Agricultural Research in the Dry Areas, Alliance of Bioversity and CIAT, CIRAD.

Gerber, P., et al. 2021. Opportunities for climate finance in the livestock sector: removing obstacles and realizing potential. Washington DC, USA: World Bank Group.

Gilbert, M., Nicolas, G., Cinardi, G., et al. 2018. Global distribution data for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks in 2010. Scientific Data 5: 180227.

Godde, C., Mason-D'Croz, D., Mayberry, D., Thornton, P. and Herrero, M. 2021. Risk of climate-related impacts on the livestock sector: a review of the evidence. Global Food Security 28. doi: 10.1016/j.gfs.2020.100488

Gurmu, E.B., et al. 2024. Comparison of Tier 1 and 2 methodologies for estimating intake and enteric methane emission factors from smallholder cattle systems in Africa: a case study from Ethiopia. Animal-Open Space 3. doi: 10.1016/j.anopes.2024.100064

Habermann, B. and Crane, T. 2024. Supporting collaborative action for sustainable solutions: locally-led adaptation as a policy instrument for climate change adaptation practices. Livestock and Climate Outlook Series Brief 2. Nairobi, Kenya: International Livestock Research Institute.

Haya, B.K., Abayo, A., Rong, X., So, I.S. and Elias, M. 2024. Voluntary registry offsets database v2024-08-31. Berkeley, USA: Berkeley Carbon Trading Project, University of California.

Hegarty, R.S., Cortez Passetti, R.A., Dittmer, K.M., et al. 2021. An evaluation of emerging feed additives to reduce methane emissions from livestock. Wageningen, The Netherlands: Climate Change, Agriculture and Food Security and the New Zealand Agricultural Greenhouse Gas Research Centre initiative of the Global Research Alliance.

Herrero, M. and Havlík, P., et al. 2013. Global livestock systems: biomass use, production, feed efficiencies and greenhouse gas emissions. Proceedings of the National Academy of Sciences 110(52): 20888-20893.

Herrero, M., et al. 2023. Livestock and sustainable food systems: status, trends, and priority actions. In: von Braun, J., Afsana, K., Fresco, L.O. and Hassan, M.H.A. (eds), Science and innovations for food systems transformation. Cham, Switzerland: Springer. doi: 10.1007/978-3-031-15703-5_20

IPCC (Intergovernmental Panel on Climate Change). 2022. Climate change 2022: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Joint Data Center on Forced Displacement, Fix, J. and Rahman, M. 2024. Host communities and refugees in the East and Horn of Africa and the Great Lakes. doi: 10.47053/jdc.080524

Kerr, R.B., et al. 2022. Food, fibre and other ecosystem products. In: Climate change 2022: impacts, adaptation and vulnerability. Cambridge, UK: Cambridge University Press.

Pereira, L.M., et al. 2020. Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. People and Nature 2(4): 1172-1195.

Richards, M. 2019. National plans to address adaptation and mitigation in agriculture: an analysis of Nationally Determined Contributions. CCAFS dataset. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Robinson, T.P., Thornton, P.K., Franceschini, G., et al. 2011. Global livestock production systems. Rome, Italy: Food and Agriculture Organization of the United Nations and International Livestock Research Institute.

Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daioglou, V., Deppermann, A., Doelman, J., Emmet-Booth, J., Engelmann, J., Fricko, O., Frischmann, C., Funk, J., Grassi, G., Griscom, B., Havlik, P., Hanssen, S., Humpenöder, F., Landholm, D. and Lawrence, D. 2021. Land-based measures to mitigate climate change: potential and feasibility by country. Global Change Biology 27: 6025-6058. doi: 10.1111/gcb.15873

Rose, S., Khatri-Chhetri, A., Dittmer, K., et al. 2022. Livestock management ambition in the new and updated nationally determined contributions, 2020-2022: analysis of agricultural sub-sectors in countries' climate change strategies. CCAFS Info Note. Wageningen, The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Rust, N.A., Ridding, L., Ward, C., et al. 2020. How to transition to reduced-meat diets that benefit people and the planet. Science of the Total Environment 718: 137208.

Rutting, L., et al. 2021. Participatory scenario planning and framing of social-ecological systems: an analysis of policy formulation processes in Rwanda and Tanzania. Ecology & Society 26(4): 20. doi: 10.5751/ES-12665-260420

Synnestvedt, T., Maviza, G. and Pacillo, G. 2024. Climate, conflict and security in global livestock systems. Livestock and Climate Outlook Series Brief 1. Nairobi, Kenya: Alliance of Bioversity and CIAT.

Thornton, P.K., Herrero, M., Nelson, G.C. and Mayberry, D. 2024. Resilient livelihoods in Africa's pastoral-agropastoral transition zones will increasingly depend on heat stress adaptation and systemic change. Nature Food. doi: 10.1038/s43016-024-01079-7Haya, B.K., Abayo, A., Rong, X., So, I.S. and Elias, M. 2024. Voluntary registry offsets database v2024-08-31. Berkeley, USA: Berkeley Carbon Trading Project, University of California.w Zealand Agricultural Greenhouse Gas Research Centre initiative of the Global Research Alliance.Herrero, M., et al. 2023. Livestock and sustainable food systems: status, trends, and priority actions. In: von Braun, J., Afsana, K., Fresco, L.O. and Hassan, M.H.A. (eds), Science and innovations for food systems transformation. Cham, Switzerland: Springer. doi: 10.1007/978-3-031-15703-5_20

Annex 1

Table A1: Examples of adaptation and mitigation measures in the NDCs

Source: Dittmer et al. 2024

Belize	Livestock (general reference)	"Reduce methane emissions from livestock by 10% by 2030 and avoid emissions of at least 4.5 kt CO_2e related to agriculturally driven land use change by 2025"
Burundi	Feed management	"Improve the composition of feed for livestock by adopting agro-sylvo- zootechnical integration systems." GHG impact of action: "Reduce methane emissions from enteric fermentation by 3% in 2025 and 2030 from 2015" (translated)
Côte d'Ivoire	Livestock (general reference)	"Control methane emissions from livestock." Reduction of GHGs (2030 vs. base scenario): 517.54 kt CO_2e (translated)
Cuba	Manure management	"Treatment of 100% of waste waters in the Cuban swine sector, reducing 8 million ktCO_2eq. in emissions annually in the period of 2020-2030."
Guatemala	Livestock (general reference), manure management, silvopastoralism	"Transform traditional extensive livestock farming into low-carbon livestock production models that can be extended nationally... Adoption of intensive rotational grazing practices, improvement of pastures (at least 40,000 ha), improved nutrition/diets, improved manure management, implementation of silvopastoral practices, more efficient water management systems are expected, best practices in animal husbandry, use of renewable energy at the farm level, among others." (Reduction of 0.637 million tons of CO_2e by 2030)
Kyrgyzstan	Manure management	"Direct reductions in GHG emissions in the "agriculture" sector are possible as a result of a decrease in the number of livestock, a decrease in methane emissions from enteric fermentation of animals, a decrease in methane and nitrous oxide emissions from manure management." Target indicators, 1000 tons of CO_2e by 2030: 68.521

INITIATIVE ON
Livestock and Climate

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