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Table of Contents

Preface

We are delighted to introduce this document, a testament to the successful partnership between two institutions dedicated to promoting long-term viability and adaptability in global livestock systems. In September 2023, the Global Agenda for Sustainable Livestock (GASL) and the Tropical Agricultural Research and Higher Education Center (CATIE) collaborated to host a series of three webinars. These sessions focused on addressing key challenges in livestock systems, particularly in terms of their enduring effectiveness and capacity to adapt to changing conditions. The webinars were designed to examine the main factors driving change in these systems and to explore their consequences at regional and global scales. Our joint effort was also geared towards pinpointing effective strategies to ensure the future health and adaptability of livestock systems. These seminars offered a crucial platform for collecting current data and diverse viewpoints, thereby equipping participants with a well-rounded perspective on the present and future state of global livestock systems.

In addition, the GASL multi-stakeholder meeting held in Chiang Mai, Thailand, stands as a testament to the far-reaching impact of these dialogues. The insights and discussions from our webinars informed critical conversations at the meeting, enriching the keynote presentation delivered by the director general of CATIE. This cross-pollination of ideas underscores the interconnected nature of our efforts and the global community's commitment to advancing sustainable livestock practices.

The three webinars addressed three main drivers affecting livestock systems now and into the future: "Environmental and Technological Innovations," "Health and Diseases," and "Geopolitical and Socioeconomic Conditions." Each webinar included presentations from experts working in the thematic areas along with the participation of stakeholders. The analysis of the webinars and discussions enabled us to articulate how the impacts of these catalysts/drivers and the solutions to address their constraints may vary across a spectrum of livestock systems, including different agroecological conditions and regional contexts.

We acknowledged the range of practices in livestock management, from extensive grazing to industrial operations, and the diversity in agroecological conditions, spanning temperate, tropical, and semi-arid ecosystems. Furthermore, we understood the importance of considering regional disparities, from the developed nations in the north to the developing countries in the south, each with its unique internal variations. This diversity presents us with challenges, but it also offers opportunities to adapt and thrive in an ever-changing world.

Here, we summarize some general solutions based on the assessment of the webinars:

- In addressing the challenges presented by the diverse drivers of change, the webinars underscored the importance of adopting comprehensive and interdisciplinary strategies. These strategies should encompass the entire livestock value chain, from raw materials and inputs to production to consumption, and should integrate modern technologies to enhance efficiency and sustainability.
- For environmental and technological innovations, the incorporation of eco-friendly technologies, digitalization, and the adoption of innovative climate-smart agricultural practices to mitigate the environmental impact of livestock systems are important. This includes addressing issues related to deforestation, biodiversity losses and the impact of climate change on water resources, soil, and air, among others.
- Regarding health and diseases, it is vital to adopt a "One Health" approach, which emphasizes the interconnection between human, animal, and environmental health. This approach promotes good health practices in livestock and ecosystems and addresses the improper use of antibiotics and other veterinary drugs. By recognizing the interdependence of various health domains, collaborative actions at the local, national, and global levels, along with the implementation of traceability systems, can help control and eradicate diseases while enhancing consumer confidence in the market. This holistic perspective ensures that health strategies consider the complex interactions between humans, animals, and their shared environment.

- This discussion of geopolitical and socioeconomic drivers emphasizes the importance of understanding global dynamics such as population growth, income expansion, and diversity in consumer perceptions. This understanding can inform trade policies and incentives, fostering a more balanced and sustainable livestock sector.

Through proactive actions, such as those summarized here, rooted in the knowledge shared in our webinars, we can navigate the dynamic and ever-evolving landscape of livestock systems. By embracing innovation, collaboration, and sustainable practices, we can ensure a resilient and promising future for livestock agriculture, benefiting local communities and the global community at large. In this way, we can ensure that sustainable livestock is part of future food systems transformation that contributes to sustainable development goals.

This first example of joint work between GASL and CATIE fostered a collaborative network for global discussion. We extend our sincere gratitude to all participants for their contributions, and we look forward to opportunities for future engagement towards sustainable and resilient livestock.

Yours sincerely,

Muhammad Ibrahim
Director General
CATIE

Shirley Tarawali
Chair Global Agenda
for Sustainable Livestock

Executive summary

Between September 5 and 11, 2023, GASL and CATIE jointly hosted a series of webinars to explore the drivers of change impacting livestock systems and their consequences for sustainability and resilience on a global and regional scale. These webinars offered a forum for stakeholders to collaboratively tackle the critical challenges in the livestock sector, focusing on formulating solutions that enhance long-term viability. This encompasses not only "sustainability" — the ability to maintain operations over time without depleting resources — but also "resilience," referring to the sector's capacity for rapid recovery and adaptation, particularly in the face of climate change and other disruptions.

The webinars encompassed three fundamental driver categories: "Environment and Technology Innovations," "Health and Diseases," and "Geopolitical and Socioeconomic Conditions." It became evident that the impact of these drivers, as well as the strategies to mitigate them, varied significantly based on diverse livestock systems, agroecological contexts, and regional disparities. While increased urbanization and income growth have stimulated the demand for livestock products, especially poultry and pig production, they have raised concerns about animal welfare and environmental sustainability due to intensified production methods.

Climate change, driven by factors such as temperature fluctuations, shifting rainfall patterns, and extreme weather events, has introduced significant challenges affecting livestock production by intensifying heat stress, pest and disease pressures, disruptions in pastures and crop performance, and soils processes. These challenges disproportionately impact vulnerable households and communities.

Recognizing the diverse landscape of farm animal production, agroecological conditions, and geopolitical contexts, there is no one-size-fits-all solution for enhancing sustainability and resilience. Various approaches, offering benefits in both resilience and mitigation, must be adapted to local needs and conditions. To address these challenges effectively, an emphasis on increased productivity, profitability, and sustainability is paramount.

Proposed strategies for pastoral systems include deploying more resilient forage germplasm, rehabilitating degraded pastures, implementing improved grazing practices, integrating herbaceous and woody legumes, and embracing silvopastoral solutions to enhance resilience, mitigate GHG emissions, conserve biodiversity, and improve animal welfare.

For mixed systems, these strategies also apply, alongside promoting enhanced integration of crops and animals, using crop residues as feed, and improving water-use efficiency and soil fertility.

For all domestic animal production, precision feeding, improved genetics, advanced reproductive technologies, and better waste management are key. Recommendations from the webinars include:

- Evaluating trade-offs between sustainable practices and socioeconomic benefits.
- Identifying proxies to monitor biodiversity, mitigation, adaptation, and water-use efficiency when implementing large-scale innovations.
- Balancing resources for both mitigation and adaptation efforts to increase resilience and livelihood security.
- Fostering convergence between solutions to address drivers of change in livestock value chains.
- A holistic approach to evaluate alternatives to livestock-based commodities.
- Harnessing digital technologies like big data and genomics for enhanced livestock production and disease control.
- Incorporating the webinars' topics into educational curricula and extension activities.
- Encouraging collective action among stakeholders to establish knowledge-sharing platforms and funding mechanisms.

Health and diseases represent another critical driver, impacting the economics of the livestock industry, food security, and public health. Zoonotic diseases pose a substantial threat, with many emerging infectious diseases originating from animals. Multiple factors, including unsustainable intensification of livestock systems, expansion into forested areas, inadequate use of antibiotics, and substandard products, contribute to the spread of disease. Recommendations from the webinars include:

- Promoting sustainable intensification of animal production systems with a focus on animal welfare and disease risk reduction.
- Embracing the One Health approach for integrated work at the human, livestock, and environmental levels.
- Effective sharing and use of data for informed decision-making in livestock and human health.
- increasing the number of veterinary laboratories using standardized methods for diagnostics.
- Encouraging private-public partnerships to address animal health concerns.

Geopolitical and socioeconomic drivers have influenced the supply and demand of livestock products globally. These drivers range from population growth, urbanization, and changes in consumer preferences to productivity factors, trade policies, and geopolitical tensions. However, their impacts are not uniform and vary among regions and countries. To address these drivers, recommendations from the webinars include:

- Recognizing the differences in the impacts and potential interventions across countries.
- Updating data on demand elasticity for livestock products.
- Understanding consumer preferences and production factors.
- Access to carbon markets to incentivize emission reductions.
- Encouraging local and foreign investments in the livestock sector.
- Efforts to forecast and share information on climate change, market conditions, and political decisions.
- Impact of financial institutions' decisions on the sector's transformation.
- Studying the impact of meat and milk substitutes on diet quality and GHG emissions.
- Conducting case studies in countries pledging carbon-neutral livestock systems.
- Encouraging Food and Agriculture Organization (FAO) country offices to promote discussions on the best strategies for raising livestock in the long-term future.

These webinars provided a platform for comprehensive discussions, fostering a deeper understanding of the complex challenges facing livestock farmers and proposing a broad array of solutions tailored to the specific needs of diverse regions. These insights aim to guide the sustainable transformation of the livestock sector in an ever-changing world.

1. Introduction

The global livestock sector is facing a series of interconnected challenges, although the perceptions and visions of the sector's future may vary depending on regions, countries, and the role each person plays in the livestock value chains, being either decision makers, academicians, researchers, technical advisors, producers of different levels and production systems, processors, retailers, consumers, and so on.

The Livestock Revolution concept proposed by the end of the last century (Delgado *et al.* 1999), suggesting that the demand for animal source foods would increase because of population growth, and changes in dietary habits due to the migration of rural people to the cities, and the increase in purchasing power, is a real situation now, and continues to rise worldwide (Komarek *et al.* 2021). However, this expansion of livestock faces significant challenges across different regions, for example, in developed countries of North America and Europe efforts are targeting the reduction of the environmental footprint and address animal welfare concerns, whereas in the developing countries of Latin America, Asia and Africa, the growth of the livestock sector is often driven by socioeconomic factors, because farm

animals are assets, a store of wealth for resilience, a factor of production in mixed farms and a means for ensuring food security (Baltenweck *et al.* 2020).

All those challenges are pushed by a diverse set of factors, some of geopolitical nature, such as trade agreements and international war tensions, differential access to markets; others socioeconomic, such as the rise of the middle class in many parts of the world, which impact consumption patterns and demand for livestock products. Others refer to environmental issues such as deforestation, biodiversity reduction, soil fertility losses, water scarcity, increased greenhouse gas emissions and climate change; and finally, others are related to animal health issues, in particular zoonosis, as well as food safety.

All those raise crucial questions about the steps needed for ensuring that livestock is healthy, productive, and safe for humans and the environment, and the long-term sustainability of livestock systems is not compromised. In summary, there is a need for analyzing livestock systems in a holistic manner, considering its entirety and complexity, looking to assure their resilience, which is understood as the capacity of systems to prepare, adapt to changing conditions, and recover rapidly from disruptions.

The series of webinars discussed here were designed and developed to analyze the primary drivers of change affecting livestock systems and their implications for sustainability and resilience at regional and global level; and to envision stakeholders collectively devising promising solutions to further enhance the sustainability and resilience of livestock systems. The webinars were an opportunity to gather up-to-date information and multidisciplinary perspectives for understanding the current situation of livestock systems at a global level, identify potential solutions to tackle the constraints faced, and set the basis for fostering collaborative strategies for the livestock sector to progress sustainably in an ever-changing world. The specific goals of this series of webinars were:

- to demonstrate and understand the primary drivers of change affecting livestock systems and their implications for sustainability and resilience at regional and global level (what change drivers are and how they affect livestock systems);
- to generate actionable proposals under the GASL four sustainability domains (environmental, social, economic, and health), which serve as a compass guiding actions that uphold ecological integrity, social equity to tackle the identified challenges ensuring sustainable and resilient livestock systems; and
- to formulate an evidence-based technical-scientific stance that can serve as a guiding framework during the GASL MSP Meeting and to provide inputs for this year's GASL regional consultations and other events such as the 2023 United Nations Climate Change Conference or Conference of the Parties of the UNFCCC, more commonly referred to as COP 28.

These webinars were a collaborative effort between the Global Agenda for Sustainable Livestock (GASL) and the Tropical Agricultural Higher Education and Research Centre (CATIE), as part of their mandates. GASL is a pioneering model of a multi-stakeholder partnership approach, bringing together governments,

non-governmental organizations, the private sector, social movements, international bodies, donors, and academia, to address the intricate challenges that pervade the global livestock sector, considering the four foundational sustainability domains, which comprehensively encompass environmental, social, economic, and health considerations. CATIE is a regional institution with a long trajectory in improving livestock systems as a means to promote Inclusive Green Development, mainly in the tropics of Latin America and the Caribbean, but with projection to other regions of the world, by generating scientific knowledge and training of new leaders, for the transformation of ecosystems, landscapes, and food systems, towards states of well-being of people and their natural and social environment management.

This series of webinars offered valuable insights for the 13th Multi-Stakeholder Partnership Meeting, titled "Multi-stakeholder collaboration to strengthen sustainability and resilience of livestock systems in response to drivers of change," held Oct. 30 to Nov. 3, 2023, in Chiang Mai, Thailand. The conference aimed to: i. examine both fast-moving and slow-moving factors influencing livestock systems; ii. explore the interconnections and feedback among these factors; iii. associate these factors with the four key domains of livestock sustainability defined by GASL (livelihoods and economic growth, food and nutrition security, animal health and welfare, and climate and natural resources use); and iv. determine areas for MSP collaboration, as guided by GASL, to initiate policy changes for global sustainable livestock, aligning with the 2022-2024 GASL Action Plan's sustainability domains.

2. Key drivers affecting the sustainability and resilience of livestock systems

2.1 Environment and technology innovation

Livestock production systems place severe pressure on the environment, through GHG emissions to air, water, and soil and via utilization of natural resources, including land, water, and fossil energy (Steinfeld *et al.* 2006). At present, the livestock sector is responsible for about 12–14.5% of the global greenhouse gas (GHG) emissions (Herrero *et al.* 2011), whereas it uses about 70% of the available agricultural land and represents about 8% of global water withdrawals (Scholten *et al.* 2013). Hence, the sector needs a profound transformation to ensure that it contributes to a rapid transition towards sustainable food systems (Herrero *et al.* 2023).

In the case of pasture-based livestock production systems, there is a need for shift from its current path of degradation of natural and social capital, toward one which generates goods (milk, beef, timber), reduces the vulnerability to climate change, contributes to maintain ecosystem attributes and render ecosystem services, including the reduction of the C-footprint by reducing GHG emissions and/or increasing C-sequestration (Murgueitio *et al.* 2011). The pillars for such change should be i. to increase plant biomass availability, quality, diversity, and persistence; ii. to control soil degradation and promote its recovery; iii. to protect and use rationally available water sources; and iv. to increase animal productivity (quantity of milk or beef per hectare). However, increasing forage availability, quality and persistence in pasture-based systems is a prerequisite to the other three.

Climate change is another key driver that affects productivity, sustainability, and resilience of livestock systems, and consequently food security; however, the interactions between climate change and livestock production are still not fully understood (Rojas-Downing *et al.* 2017). Some of the impacts of climate change on livestock production are associated with changes in the quantity and quality of available feeds in response to drought or flooding events; constraints in fresh water supply; heat stress, particularly in high-yielding and non-adapted animals; and the dynamics and incidence of livestock diseases and disease vectors, among others (Thornton *et al.* 2009).

Several technology innovations are available to tackle such problems. To increase the quantity and quality of available feed resources in the case of ruminant systems, a combination of grasses, legumes, trees, palms, shrubs, and edible weeds is a must, as it helps to increase net photosynthesis and consequently forage biomass production, improve nutrient cycling, recover soil biota and fertility, and conserve/recover biodiversity (Pagiola *et al.* 2005; Trilleras *et al.* 2015; Solorio *et al.* 2017). In this context, there is a diversity of forage germplasm and improved management practices that could be used for enhancing productivity in well-established pasture systems and/or the rehabilitation of degraded pastures in tropical and temperate areas (Peters *et al.* 2013; Enríquez-Quiroz *et al.* 2021); however, problems of pasture degradation will reappear if mistakes are made identifying the genotypes that fit better to each site conditions, if failures during the establishment phase occur, or if inadequate grazing management practices are applied in newly implanted pastures, among other factors (Días-Filho, 2007; Pezo *et al.* 2018).

In response to climate change, more attention has been paid to the water footprint in livestock systems, as well as to the increased water demands of livestock, given that it increases under heat stress conditions (Thornton *et al.* 2009). For that reason, significant improvements need to be made in water productivity by improving feed management and sourcing, increasing diet quality, improving pasture management, reducing land degradation through control of stocking rates, implementing water harvesting techniques and others (McDermot *et al.* 2010). Also, the presence of shade trees in pastures, which is a traditional silvopastoral option in many areas of the world, helps to reduce water needs by reducing evapotranspiration in vegetation, and at the same time enhances animal welfare by controlling heat stress (García-Cruz *et al.* 2013; Pezo *et al.* 2018; Huertas *et al.* 2021; Deniz *et al.* 2023).

In the case of grains, tubers and other starch and protein sources used as supplements in ruminant pasture systems and intensive

monogastric systems, as well as in forage production systems, several efforts have been made by crop scientists to mitigate the risks associated with climate change by: selecting crop species and varieties that use less water and are more resistant to drought and pests; using minimum or zero tillage for improving soil ability to hold moisture, reduce water runoff, and reduce surface evaporation; as well as by applying water management technologies, such as drip irrigation and water-harvesting techniques (Ibidhi and Salem, 2020; Belmin and Malézieux, 2023). Also, changes in cropping systems in terms of composition, planting dates and arrangements, and land/seedbed preparation have proved to be practical interventions to reduce the water footprint in crops (Selvaraju, 2012). Those are considered in agroecology and climate-smart agriculture models, which although they have some conceptual differences, in real life do not conflict with each other since they are often promoted concomitantly (Belmin and Malézieux, 2023).

The potential impacts of the innovations mentioned above and others for increasing productivity, economic performance, and adaptation/mitigation of climate change in livestock systems, as well as on the contribution of such systems to halt deforestation and increase the presence of trees in livestock farms is well documented in the literature, but the adoption of many of them has remained relatively low, despite their potential to create better socio-economic conditions for the farmers, as well as their contribution for generating local and global ecosystem services, particularly in the case of silvopastoral options (Dagang and Nair, 2003; Ibrahim *et al.* 2006).

Some enabling mechanisms for promoting the adoption of such technology innovations, particularly silvopastoral options, are: i. to promote coordinated research and technology transfer efforts involving institutions with mandates and expertise in livestock production, forestry, and environmental issues; ii. to encourage capacity building efforts at all levels on the key drivers affecting the sustainability and resilience of livestock systems; iii. to enhance a more efficient use of information and communication technologies for facilitating the dissemination of technology innovations aimed at improving livestock systems in a sustainable manner; iv. to advocate for the application of participatory learning and action research for testing promising options in different agroecosystems; v. to implement successful pilot projects to demonstrate the potential of the identified promising innovations, followed by large-scale projects aimed at mainstreaming lessons learned; and vi. to develop the legal framework, policy, and planning to enable adoption of climate-smart innovations (Pezo *et al.* 2018).

2.2 Health and disease

The globalization of infectious diseases has been occurring frequently and at an unprecedented speed in the last two decades (Mackey *et al.* 2014); however, although this problem was on the agenda of scientists and health decision makers, probably others including the general public became more aware of this problem after the COVID-19 crisis emergence in early 2020, and this even affected global stock market liquidity, while information campaigns on the novel coronavirus facilitated trading activity after the shock (Zaremba *et al.* 2021).

In general terms, endemic diseases have historically declined in wealthy countries because of improvements in disease management and disease risks preparedness systems, enhanced public concern over animal welfare

and environmental pollution, and higher availability of technological and methodological options for disease management and control. To some degree, the same applies to the intensive systems, mainly of poultry and pigs, that have taken relevance in the last few decades in developing countries as a response to the opportunities opened by the Livestock Revolution. However, increases in the incidence of animal health problems at farm level are associated with animal crowding, improper management of residues, absence or weak application of biosecurity measures, and in the case of consumers, foodborne disease risks are enhanced by the poor application of hygiene measures in the processing and retailer markets nodes (Perry *et al.* 2013).

A different situation is faced in many developing countries by the traditional livestock-dependent smallholder and pastoralist systems, which are stuck in a poverty trap of conflict, poor governance, low education, and limited access to veterinary and human health services. Those inevitably constitute hot spots for endemic diseases, periodic epidemics (such as Newcastle, which regularly wipes out poultry in rural areas), and neglected zoonoses, which significantly impact human health. Because of the low densities of livestock, their remoteness, limited access to larger markets, and the slow change in husbandry practices, these are probably not hot spots for emerging diseases; however, they are highly vulnerable due to poorly designed disease control measures and lack of disease diagnostic and technical advice services (Herrero and Thornton, 2013; Grace *et al.* 2017; Nkonki-Mandleni *et al.* 2019).

In recent years, the "globalized" environment of interdependent trade, travel, migration, and international economic markets, among other factors, have played an important role in the rise, emergence, and reemergence of infectious diseases. Among those, the zoonotic diseases (i.e., those infectious diseases that can be transmitted from animals to humans) account for most emerging and reemerging infectious diseases occurring due to increased contact between humans and animals as a by-product of development, industrialization, and encroachment on wildlife habitats, resulting in a dynamic upward trajectory of these diseases (Jones *et al.* 2013). Yet many of these emerging and reemerging infectious diseases are also "neglected," meaning they impact the world's poorest people and lack adequate funding and innovation for prevention and treatment, with some not adequately identified or studied (Mackey *et al.* 2014).

The increase in demand for animal source foods has led to the expansion of livestock systems into forested areas in many parts of the developing world, instead of rehabilitating and intensifying the use of areas already dedicated to this purpose. Such expansion has resulted in deforestation and fragmentation of ecosystems and wildlife habitats, enhancing contacts at the human-livestock-wildlife ecosystem interface; with consequences for the emergence of zoonoses, although the understanding of the mechanisms underlying their emergence remains rudimentary (Allen *et al.* 2017). These activities often come with other changes, such as new human settlements, road building and movements of people and products, which further increase human access to wilderness areas, increasing the use and exploitation of wildlife and bringing greater risks for zoonotic diseases incidence, because while wildlife may be a source of the disease, domesticated animal sources can act as amplifiers of pathogens emerging from the wild (UNEP and ILRI, 2021).

Many zoonoses are climate-sensitive and several of them thrive in warmer and wetter, more disaster-prone zones, conditions that are becoming more frequent due to climate change. Under those scenarios, there is a higher presence of parasites (organisms associated with many of the neglected tropical diseases) and their vectors that ultimately infect human hosts. That is another reason why in recent years zoonotic diseases have increased (Chan *et al.* 2011; Karesh *et al.* 2012; Chala and Hamde, 2021). Other factors considered as drivers for the exacerbated emergence and re-emergence of vector-borne infectious diseases are the ongoing evolution of pathogens, proliferation of reservoir populations, as well as self-medication, the use of non-prescribed antimicrobial drugs, or the sub-utilization of those (Dafale *et al.* 2020; Chala and Hamde, 2021).

Given the considerable challenges in the diagnosis and management of endemic, neglected and emerging zoonotic diseases, interest has been growing in the potential benefits of adopting a more integrated One Health approach involving both human and animal health as well as environmental sectors (Halliday *et al.* 2015; UNEP and ILRI, 2021). Collaborative research networks and collective action on zoonotic and vector-borne emerging and re-emerging infectious diseases remain the most crucial strategy in addressing the root problems for long-term plans. Sustained collaboration between medical, veterinary and wildlife authorities is necessary to improve surveillance and control of zoonotic diseases (UNEP and ILRI, 2021). In this regard, applying the One Health principles seems to be the route; because, even though nowadays, numerous emerging, re-emerging, and stable vector-borne infectious diseases are becoming well-managed, future efforts to block the emergence of new diseases seem uncertain, and this should be an alert for an uninterrupted fight against emerging vector-borne infectious diseases (Chala and Hamde, 2021).

The successful application of the One Health approach requires that we: i. raise awareness and increase understanding of zoonotic and emerging disease risks and prevention at all levels of society; ii. expand scientific enquiry into the complex social, economic, and ecological dimensions of emerging diseases, including zoonoses; iii. improve cost-benefit analyses of emerging disease prevention interventions; iv. develop effective means of monitoring and regulating practices associated with zoonotic diseases, including food systems from farm to fork; v. provide incentives for sustainable food systems, even for those including wildlife source foods; vi. include proper accounting of biosecurity measures for all types of livestock production systems; vii. support integrated management of landscapes that enhance sustainable co-existence of agriculture and wildlife, including investments in agroecological methods of food production that mitigate waste and pollution while reducing risk of zoonotic disease transmission; viii. strengthen existing capacities and build new ones among health stakeholders and help them to understand the human, animal, and environmental health dimensions of zoonotic and other diseases (UNEP and ILRI, 2021).

2.3 Geopolitics and socioeconomics

2.3.1 Population and economic growth

The current global population of 8 billion is expected to grow up to 9.3 billion in 2050 and 10.1 billion in 2100 (Sibly and Horne, 2002); however, it is expected that the growth rate will decline in developed countries and increase in developing countries (Lee, 2011; Revell, 2015); the same trend has been observed for rural vs. urban settings (Grimm *et al.* 2008). On the other hand, the average income has been rising worldwide, although income inequality within countries has registered a clear upward trend on a global level since the 1980s (Goda, 2013). All these factors have resulted in an increased demand for animal-source foods and other protein sources globally, with different trends between developed and developing countries (Kim *et al.* 2019, Ismail *et al.* 2020), with the rise in demand for animal proteins occurring mostly in emergent and developing countries.

The rapid growth of demand for livestock products, globalization and liberalization of markets, and developments in transportation, cold chain, and meat processing and packaging technologies have been combined to promote global trade in livestock products (Smith *et al.* 2010; Enahoro *et al.* 2021). During the period from 1961 to 2006, the share of livestock products in the global agricultural export value rose from 11 to 17%, and now the livestock sector represents about 40% of the agriculture GDP globally. However, the sector faces several challenges related to its contributions to climate change and environmental degradation, disease risks to both humans and livestock, and social and consumer-related demands about product type, quality and safety, and animal welfare, among others.

In terms of GHG emissions throughout the animal-source food supply chains in 2019, reached 30 ± 9% of total anthropogenic GHG emissions, largely triggered by the growth of beef and dairy consumption in rapidly developing countries, while per capita emissions in developed countries declined (Li *et al.* 2023). Population growth and per capita demand increase were key drivers to global emission increase (+30% and +19%, respectively) while decreasing emission intensity from land-use activities was the major factor to offset emission growth (-39%). Hence, incentivizing consumer and producer choices to reduce emission-intensive food

products may help to mitigate the impacts on climate change (Li *et al.* 2023). Additionally, afforestation in land areas freed due to changes in the diet portfolio will lead to further emission removals of 4–37% (Chan *et al.* 2022).

2.3.2 Environment-related policies

Several policy interventions have been promoted as enablers for the adoption of technology innovations — such as silvopastoral systems — that could help to increase productivity, improve economic performance, and mitigate climate change in livestock systems. The adoption of these interventions has the potential to create better socioeconomic conditions for farmers while contributing to generate local and global ecosystem services (Ibrahim *et al.* 2006). Incentives can be either financial or non-financial in nature (Pezo *et al.* 2018), such as incentives for reforestation, payment for ecosystem services, and green credits.

The funds allocated to compensate landowners for changing land use systems on their properties from any agricultural use to forest is a type of payment for the environmental services that the forests could provide such as the mitigation of GHG emissions, hydrological services including water provision, biodiversity conservation, and the provision of scenic beauty for recreation and ecotourism (Ibrahim *et al.* 2010). In some cases, a portion of the forest incentives received by livestock farmers was used to intensify animal production activities as they had to maintain the same number of animals on a smaller area of pastures. Indirectly, forest incentives also contributed to the adoption of better management practices in livestock farms, such as the rehabilitation of degraded pastures, the use of more intensive grazing management practices, and the implementation of other silvopastoral innovations (Rivera-Céspedes *et al.* 2016). In the case of Costa Rica, at the initial stages of the forest incentives program, large farmers and forest owners were the main beneficiaries of forest incentives (Zbinden and Lee, 2005); however, after agroforestry/silvopastoral options were recognized as component to the National Forestry Financing Fund in 2004, significant changes occurred resulting in a considerable increase in the number and diversity of trees planted and in the reduction of seasonal burning in smallholder farms (Cole, 2010).

Financial incentives for ecosystem services have shown effectiveness in promoting the adoption of climate-smart innovations within livestock systems. A project run by CATIE with partners in Costa Rica, Colombia, and Nicaragua, funded by the World Bank Group, and known as the GEF Silvopastoral Project, demonstrated how monetary incentives can effectively accelerate the adoption of silvopastoral innovations (Pagiola *et al.* 2005, Casasola *et al.* 2007, Calle *et al.* 2013). Moreover, available data suggest that Payments for Environmental Services (PES) had an additional impact on the prevention of deforestation (Daniels *et al.* 2010), and the practices promoted through the PES program in livestock systems in Costa Rica persisted even more than 10 years after the project finished, and those changes have not been reversed (Rasch *et al.* 2021).

In the past, offering subsidized credits to livestock farms was one of the main factors that contributed to their expansion into forested areas (Kaimowitz, 1996; Roebeling and Hendrix, 2010). However, having access to lines of credit with lower interest rates to promote environmentally friendly investments — so-called "green credits" — has proven to be effective for increasing forest cover in livestock farms. In Nicaragua, NITLAPAN´s Local Development Fund (FDL) created a green credit line for livestock farmers interested in introducing climate-smart

innovations such as silvopastoral systems, resulting in higher adoption of those technologies, with favorable impacts not only on animal productivity, income, and reduced GHG emissions, but also on biodiversity conservation (Villanueva *et al.* 2010; Dupraz, 2020). Current initiatives to transform the livestock sector, e.g., the Honduran Ministry of Agriculture and Forestry (MAF) livestock project implemented by CATIE, have recognized the importance of creating flexible financial products to catalyze the adoption of technologies and best practices; however, these instruments need to be accompanied with default risk mitigation strategies to help the banking system finance the decarbonization of a sector.

Another relevant option is to have access to the Climate Change Initiatives. In that sense, many countries in Latin America and other regions of the world have identified the livestock sector as part of their Intended Nationally Determined Contributions (INDCs) for Climate Action. In fact, a recent study showed that 36% of the countries that submitted INDC for Climate Action proposals included livestock mitigation measures (Rose *et al.* 2022). These decisions are catalyzing new government and private sector initiatives to promote structural adjustments to the current livestock production systems including the adoption of silvopastoral innovations, as in the case of Costa Rica, Colombia, Mexico, and more recently Honduras. While there have been efforts in many countries to prepare Nationally Appropriate Mitigation Actions Initiatives for the livestock sector (NAMA-Livestock), only Costa Rica and Uruguay have already developed concrete low C-emissions strategies for the sector (MAG-Costa Rica, 2015; FAO/UNDP, 2017).

2.3.3 Trade policies and arrangements

Another important socioeconomic driver for enhancing sustainability and resilience of

livestock systems is trade. In that context, free trade agreements have taken more importance in recent years, but their impacts on exporting and importing countries are very complex. For example, modeling the free trade agreement between the European Union (EU) and MERCOSUR for beef showed that imports from MERCOSUR will result in a significant loss for the EU meat sector; however, the EU meat exports to third country destinations would increase, while Mercosur's exports of beef to non-EU destinations would decline (Burrell *et al.* 2011).

Another aspect to be considered is how these agreements may impact environmental conditions in signatory countries. The analysis of three cases — EU–Mercosur Agreement, the EU–Canada Comprehensive Economic and Trade Agreement (CETA), and EU–Vietnam Free Trade Agreement (EUVFTA) — found that a few mandatory standards lack a comprehensive legal framework to uphold/enhance environmental protection, hence results on that respect were not as expected (Heyl *et al.* 2021).

Another example of an approach to favor the environment through livestock trade agreements is the Brazilian Cattle Agreement (BCA), signed by the three largest beef processors in Brazil, committing to avoid buying animals from ranchers engaged in deforestation, in forced labor use, and in encroachment on indigenous and protected lands in the Amazon region. However, the results obtained were not as expected because the agreement reached only direct suppliers to the processing plants, but those may buy calves for fattening from ranchers who do not comply with the BCA requirements; because a Monitoring, Reporting and Verification (MRV) system for the providers of growing animal was lacking (Shimada and Nepstad, 2018).

Trade in livestock products and inputs such as feeds has also been affected by geopolitical conflicts such as the Russia-Ukraine war, internal insecurity conditions due to civil wars, drug trafficking (McSweeney *et al.* 2017), and diseases such as the COVID-19 pandemic and the dissemination of the African Swine Fever (ASF) to China and some European and Southeast Asian countries (Ma *et al.* 2021). The first case affected the trade of cereals and their byproducts (Abay *et al.* 2023), and the last opened opportunities for exporting pork from ASF-free countries, as in the case of Costa Rica exporting pork to China.

2.3.4 Service delivery and organizational arrangements

Public investments and support services to the livestock sector, especially for smallholders, are frequently limited, and this situation has been exacerbated by the fiscal crunch experienced by most governments in developing countries over the past few decades (Scoones and Wolmer, 2006; Mena *et al.* 2020)). In response to the constraints faced by governments on funding service provision to livestock farmers, two options have been promoted in many countries: privatization and decentralization (Pica-Ciamarra, 2005). However, both approaches may become ineffective as far as the roles of the public and private sector, including NGOs, in service provision are not clarified. In the case of animal health, services present a mixture of private and public goods. For example, clinical veterinary services and distribution of drugs can be considered private goods, whereas disease surveillance and prevention and food safety are classified as public goods (Scoones and Wolmer, 2006).

Regarding changes in the approach of extension services offered to farmers for improving the sustainability of livestock systems, the

Farmer Field Schools is one that has proven successful (Pezo *et al.* 2007; Aguilar *et al.* 2010; Davis *et al.* 2012), because of the involvement of farmers in co-designing their processes of change in practices and redesign of their farming systems, which are crucial to agroecological transitions (Bakker *et al.* 2022; Meynard *et al.* 2023). The adoption of ICTs (information and communication technology) has helped to enhance livestock farm productivity in many places, with mobile phones, computers, radio and television being the most frequently used; however, the lack of financial support, network coverage, knowledge and information, and the limited availability of programs aired on radio and television has limited the wider impact, particularly in developing countries (Mdoda and Mdiya, 2022).

2.3.5 Synthetic alternatives to animal source foods

Another factor that reduces meat consumption is the development of synthetic alternatives to animal and vegetable proteins to replace natural animal protein sources. These developments respond to the fact that the demand for animal proteins will continue to grow because of the associated health benefits of consuming meat, milk, and eggs; however, increases in the vegan, vegetarian, and flexitarian populations have propelled the usage of plant proteins in food products as an alternative (Ismail *et al.* 2020). Also, the fact that eggs and dairy are among the "big eight" major allergens recognized by the U.S. Food and Drug Administration has pushed the use of cultured meat and plant protein sources as the proposed sources for people allergic to those animal food sources (Chriki and Hocquette, 2020).

The growth of alternative protein sources has also received attention because of the larger environmental and climate footprint attributed to animal proteins as compared to plant-based foods, as well as because of animal welfare issues, among other reasons. However, there is still controversy regarding the reasons given in favor of each option (Parlasca and Qaim, 2022). For example, when comparing the environmental impacts of cultured meat with plant-based foods, the available estimates showed that cultured meat has higher GHG emissions and energy use compared to unprocessed plant-based protein crops, such as beans and peas; but emissions are comparable with processed vegetarian meat substitutes (Tuomisto, 2019). The key point is that still there is no consensus on the potential advantages in terms of GHG emissions of lab-grown meat compared to conventional meat on a short-term or long-term basis (Chriki and Hocquette, 2020). Other points to be considered for the future development of cultured meats is acceptance by consumers in terms of taste, religious and cultural principles, and market prices, among other reasons that may influence their acceptance and the willingness of consumers to buy them (Bryant and Barnett, 2018).

3. Examples of successful cases

The preceding section has provided us with an in-depth understanding of the essential drivers supporting sustainability and resilience in livestock systems. The livestock sector is facing a rapid pace of change and uncertainty, with multiple crises, such as pandemics, climate change, environmental degradation, growing inequality, hunger, and poverty rise, among others. It is our responsibility to identify pathways for adjustment and transformation aimed at improving the long-term viability of this sector. To address these challenges, GASL promotes interdisciplinary work, considering the four interrelated domains of sustainability for livestock systems: i. food and nutrition security; ii. livelihoods and economic growth; iii. climate and resource use; and iv. animal health and welfare. Potential actions to tackle these drivers vary with the diversity of livestock systems and will depend on more than one intervention acting synergistically.

In this "successful cases" section, we will immerse ourselves in real-life experiences of livestock farmers, researchers, and communities that have successfully

found solutions to address the pressures caused by different drivers. Through these cases, we will explore how these principles have translated into effective practices and remarkable outcomes, thereby inspiring others to adopt similar approaches in pursuit of a more promising future for the livestock industry. Many of these cases are directly linked to the webinar series that took place throughout the month of September, the documentation of which can be found in Annexes 1, 2, and 3 at the end of this paper. These webinars served as a platform for sharing best practices and fostering collaboration among livestock stakeholders, and the success stories featured in this section serve as tangible evidence of the positive impact of these knowledge-sharing events. By referring to the corresponding annexes, readers can access in-depth insights and additional details on the specific strategies and outcomes discussed in the cases, further enriching their understanding of the successful approaches adopted by various individuals and organizations within the livestock industry.

3.1 Examples of successful cases to alleviate environmental pressures on livestock systems: The reduction of the C-footprint in livestock systems in tropical America

The contribution of the livestock sector to the global GHG emissions is about 14.5-16%, and among those, methane is the main contributor. For example, in Costa Rican dairy systems methane represents between 69 and 82% of total emissions (Wattiaux *et al.* 2016). However, the level of net emissions could vary as a function of pasture management practices and the presence of woody perennials in the livestock system, and as part of silvopastoral options or forests in farmlands, the strategic supplementation and controlled use of external inputs, and waste management interventions, among other factors. Here we present two cases referring to the carbon footprint in tropical cattle systems.

Case 1.

Contribution of tree cover to the compensation of greenhouse gas emissions from dairy farms in the southeast of Guatemala (Villanueva *et al.* 2023)

The objective of this study was to identify the main sources of GHG emissions and to determine the carbon balance in milk-producing farms in the southeastern region of Guatemala, where 30 farms with different levels of technological innovation were selected and where biophysical and socio-economic information was collected to estimate GHG emissions using IPCC equations (IPCC, 2006). Carbon sequestration was estimated through the monitoring of temporary plots in different land uses, considering systems with high and low incorporation of innovations.

The main source of emissions in the livestock farms was enteric fermentation, followed by use of fertilizers, manure, fuels, and other energy sources. Enteric fermentation was the highest source of emissions in more traditional farms, whereas fertilization was the main source of emissions in those with a high level of innovation. The intensity of emissions per kilogram of milk was lower in farms with high innovation, while traditional systems showed lower emissions per kilogram of beef. In both cases this was explained by higher productivity. Fifty-three percent of the farms presented a positive carbon balance, mainly explained by the compensation provided by secondary forests and scattered trees in pastures. In the short term, farms with a lower C-footprint will have a positive image for those concerned with GHG emissions, hence would be good candidates for getting access to any environmentally based incentives.

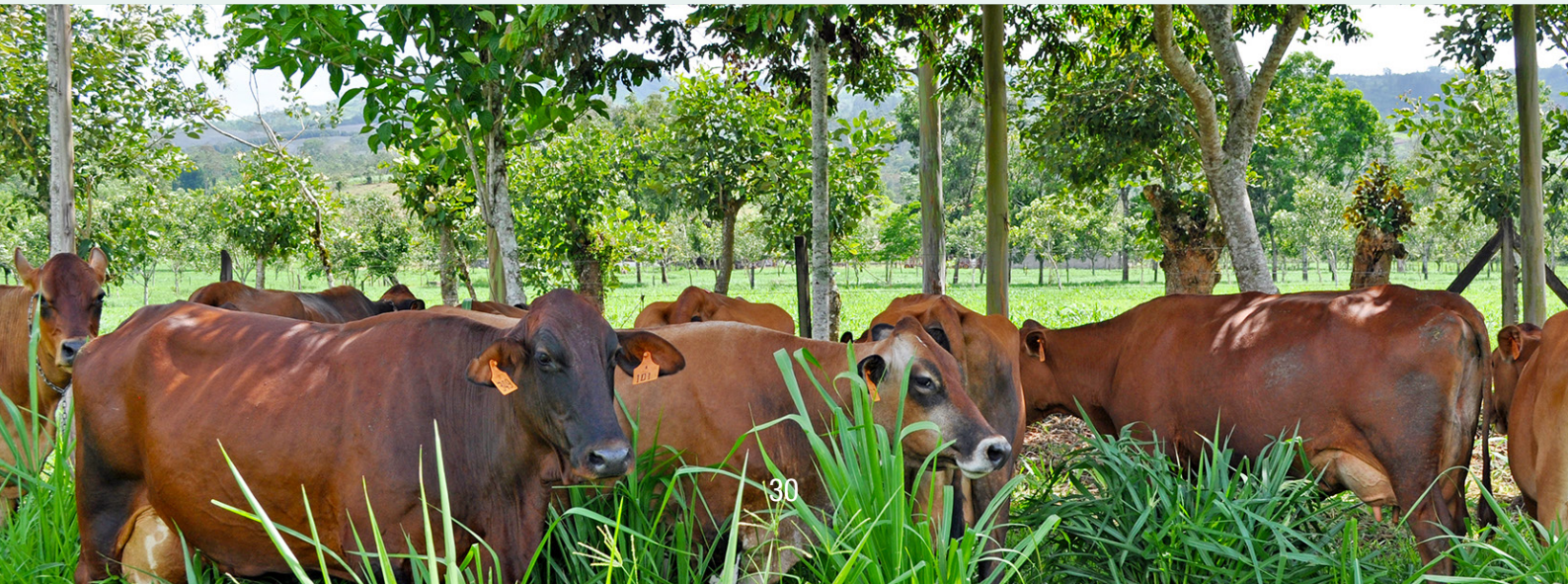
Case 2.

Silvopastoral Systems Ecological Strategy for Decreases C Footprint in Livestock Systems of Piedmont (Meta), Colombia (Parra *et al.* 2022)

The objective of this study was to evaluate the carbon footprint for different pasture types that are the basis for beef production in the Llanos of Colombia. In this study, improved pastures were covered by *Urochloa decumbens*, and degraded pastures were found in paddocks initially planted with *Urochloa brizantha*, which lost its production potential due to improper grazing management practices. Other silvopastoral systems considered were: *U. decumbens* + *Acacia mangium*; *U. decumbens* + *Gliricidia sepium*, *U. decumbens* + *Mangifera indica*, *U. decumbens* + *Guadua angustifolia* and *U. decumbens* + *Citrus sinensis*. Emissions in all these systems were estimated using IPCC equations (IPCC, 2006). Carbon sequestration was estimated through soil organic carbon (SOC), and the accumulation in roots and in the aerial biomass in the case of woody species. The carbon balance was estimated by the difference between emissions and sequestration and the C-footprint using IPCC methods (IPCC, 2006).

In all systems, the largest GHG emissions were from enteric fermentation (CH_4), manure management (N_2O) and feeds (CO_2). GHG emissions per kg of live weight (LW) were higher in the silvopastoral systems, followed by improved and degraded pastures (9.14, 7.17 and 4.4 $kgCO_{2eq}$ $kgLW^{-1}$, respectively). Those beef production systems with silvopastoral options resulted in the lowest carbon footprint, with the best results in the case of *U. decumbens* + *Acacia mangium*, but in all silvopastoral systems the amount of carbon stored in the root and aerial biomass overcompensated emissions.

This study, like many others, confirms the importance of promoting silvopastoral systems using adapted improved pastures and woody perennials to optimize the GHG mitigation potential in livestock systems. The GHG neutralization capacity of silvopastoral systems can contribute to meeting government emission reduction targets, and to reconciling the increase in livestock production with the reduction of GHG emissions to the atmosphere.



3.2 Examples of successful cases to alleviate health and disease pressures on livestock systems

About 60% of human infections have an animal origin, and among the new and emerging human infectious diseases, some 75% have jumped from animals to people. These diseases are more common in developing countries. Emerging diseases are hugely problematic, with some becoming epidemic (affecting many people within a region), others becoming pandemic (spread over several countries and continents and affecting large numbers of people around the world). In this section of the report are included two cases that illustrate the relevance of zoonotic diseases as drivers of change affecting the sustainability of livestock systems. The first case refers to an epidemic zoonotic disease that affects several countries in Sub-Saharan Africa, known as African trypanosomiasis or "sleeping sickness" in humans; and the second is an analysis of the impact of COVID-19, a pandemic disease of recent appearance (UNEP and ILRI 2021), on the sustainable intensification of forage-based beef and dairy value chains in Colombia.

Case 1.

The African Trypanosomiasis: Geographical distribution changes due to climate change (Nnko *et al.* 2021) and progress eliminating the disease in humans (Franco *et al.* 2022)

Most climate change predictions indicate that temperatures will continue increasing in the following decades, and these increases have the potential to cause species habitat modification, including range expansion or contraction in addition to altering their relationships with the biophysical environment. Predicted rise in temperature is also expected to transform dynamics of African trypanosomiasis, either by altering the vectors' and pathogens' geographical range, or their development and mortality rates, resulting in changes on the occurrence of sleeping sickness ("nagana") in humans living in areas where tsetse flies are present.

The use of models for predicting changes in distribution of the vector (three species of Glossina) is a tool for evidence-based decision making to predict the potential for infection of animals and humans with Trypanosoma brucei, the parasite responsible for the disease. In the case of the Maasai Steppe in Tanzania, it is expected that in the year 2050, areas with suitable climate for the vector will decline to from 23.13 to 12.9%, because the mean maximum temperature of the warmest month (34° C) and mean minimum temperature of the coldest month (17° C) are beyond the temperature thresholds for the vector (Nnko *et al.* 2021). For other parasites (e.g., ticks) the rise in mean temperature is resulting in the incidence of tick-borne diseases at higher altitudes in tropical countries.

In the case of human African trypanosomiasis, such information on animal trypanosomiasis will be helpful for plans to eradicate the disease, but must be supported by an effective surveillance system, including the control of cryptic reservoirs such as asymptomatic human carriers and infected animals. It will also be supported by the development of new tools such as a single-dose oral treatment for both stages of the disease, the generation of rapid diagnostic tests, and high throughput referral tests performed in dry blood spots not requiring sophisticated transport conditions such as ELISA and other molecular tests (Franco *et al.* 2022).

Case 2.

The impact of COVID-19 on the sustainable intensification of forage-based beef and dairy value chains in Colombia: a blessing and a curse (Burkart *et al.* 2022)

The COVID-19 pandemic created disruptions in all agricultural value chains, including livestock, a sector that was affected at least in the short term by increasing input prices and reduced consumer demand affecting the livelihoods of low-income cattle producers. Sustainable intensification of the cattle sector has been part of the political agendas of most Latin American countries for at least a decade prior to the pandemic and has become a central element for governments to meet the commitments made under the Paris Agreement of the United Nations Framework Convention on Climate Change for greenhouse gas emission reductions. At the beginning it was proposed that the COVID-19 pandemic affected the sustainable intensification efforts, i.e., when it comes to technology adoption, product differentiation, information sharing, and financing. However, this study was designed to assess if it effectively affected the sustainable intensification of the cattle sector in Colombia, putting emphasis on both potential negative impacts and future opportunities.

The study demonstrated that COVID-19 had the following short-term impacts on the sustainable intensification in Colombia: i. increased input prices; ii. limited access to inputs, credit, and technical assistance; and iii. reduced incomes that limited investments in sustainable intensification along the value chains. It was found that reduced resources for research and development funding, unavailability of skilled and experienced staff, restrictions on travel and person-to-person interactions, in tandem, have caused setbacks in the development and application of sustainable technologies and programs. However, in some ways part of those challenges were addressed by increasing the use of communication technologies, although difficulties were faced because many farmers did not have access or were not trained for the use of such technologies.

A long-term shift of consumer demand towards more sustainable animal products is occurring and expected to continue, and this should lead to new opportunities for sustainable intensification.

3.3 Examples of successful cases to alleviate geopolitical and socioeconomic pressures on livestock systems

Geopolitical and socioeconomic conditions have a relevant impact on the sustainability of livestock systems. For example, population growth and changes in per capita consumption of animal source foods due to the improvement of income and urbanization are key determinants of their increased demand; the new trade conditions resulting from commercial agreements between countries and regions, problems associated to geopolitical crisis, as well as regulation due to environmental effects of certain forms of livestock production, as well as changes in consumer preferences, affect the access to markets for countries as a whole or groups of farmers within countries in particular. In this section, the first case refers to risk management strategies by smallholder livestock farmers in sub-Saharan Africa, including the use of new information and communication technologies that are increasingly more available in the developing world. The second case deals with the development of meat substitutes produced artificially as a means to respond to environmental and ethical concerns by a sector of consumers, and how these alternatives have faced constraints due to consumer preferences, as well as religious principles that need to be considered, among other factors. Also, the cases analyzed reveal the need for further studies to assess if those alternatives effectively reduce greenhouse gas emissions, the economics of the production processes, as well as food-safety concerns about alternative meat products.

Case 1.

The Resilience of Smallholder Livestock Farmers in Sub-Saharan Africa and the Risks Imbedded in Rural Livestock Systems (Gwaka and Dbihlela, 2020)

Smallholder livestock farmers are important in the research and policy development agenda of developing countries, like the ones in sub-Saharan Africa, not only because they represent most farmers, but also because of the everlasting issue of food insecurity which stems from many factors including natural hazards, conflicts, economic crises, diseases, and politics. Smallholder communities have developed unique and unconventional risk management strategies to cope with those challenges; however, the complexities of the risks faced demand new, context-appropriate, and advanced strategies. Finding that solutions are frequently more complicated because of a reactive, post-risk occurrence is the dominant risk management approach applied by smallholder livestock farmers.

Several options are part of the risk management strategies currently applied by smallholder livestock farmers, such as diversification of livelihood options, including off-farm work. However, in most cases livestock remains at the center of household income generation and food security. Lack of access to technologies and information, poor infrastructure, and limited access to markets with fair prices, as well as environmental factors that contribute to unpredictable system dynamics, play a key role in deterring sustainable smallholder livestock farming.

This study revealed the potential for using emerging innovations by smallholder livestock farmers, as part of their proactive risk management activities. Depending in part on cellphone coverage, these become a powerful tool for enhancing their risk mitigation potential and value chains. It is true that many traditional farmers have natural resistance to change, but this could be tackled by applying proper training and education strategies. The study also recommends the use of positive deviance approaches that look at those smallholder livestock farmers who are doing well and enhancing their resilient indigenous know-how to achieve better results under constraining conditions. This can be enabled by coordinated approaches that tap into their existing leadership structures, risk-sharing approaches, and communal knowledge bases.

Case 2.

Factors Affecting Consumers' Alternative Meats Buying Intentions: Plant-Based Meat Alternative and Cultured Meat (Hwang *et al.* 2020) and The Myth of Cultured Meat: A Review (Chriki and Hocquette, 2020)

A sector of consumers, particularly in developed countries, have started to become aware of the negative aspects of conventional meat production, including concerns about environmental issues, animal welfare, and consumer health. Alternative "meats," i.e., cultured meat (also called in vitro, artificial, or lab-grown meat), and plant-based meat alternatives have been introduced recently for consumers who do not wish to change their diet but have concerns about eating real meat. A rapid growth of the alternative meat market may occur, posing a threat to the conventional meat market; therefore, it is necessary to identify the features of alternative meat that affect consumers' purchasing intentions.

The review by Chriki and Hocquette (2020) concluded that there have not been major advances in the production of cultured meat. In terms of technical issues, research is still required to optimize cell culture processes. It is also almost impossible to reproduce the diversity of meats derived from various species, breeds, and cuts. Regarding the potential health benefits, it is suggested that cultured meat produced from muscle cells may be safer than conventional meat; however, with the high level of cell multiplication occurring in artificial meat production, it is likely that some dysregulation happens like in cancer cells. Likewise, the control of its nutritional composition is still unclear, especially for micronutrients and iron. Regarding environmental issues, the potential advantages of cultured meat for greenhouse gas emissions are a matter of controversy, although less land will be used compared to livestock, ruminants in particular, and no CH_4 emissions occur by producing cultured meat, but there is a contribution of CO_2 due to the use of fossil energy to warm cultured cells. When analyzing the GHG emissions in terms of carbon equivalent, there is no consensus about GHG emissions of lab-grown meat compared to conventional meat; a first study gave an advantage to cultured meat, whereas a second study was inconclusive.

Regarding consumer preferences, results showed that sustainability and food neophobia are two of the factors, and food curiosity, unnaturalness, and distrust of biotechnology are common factors affecting consumers' purchasing choices. Other aspects to be considered in the future are legislation for regulating the production and marketing of cultured meat, and the role of religious principles in accepting or rejecting these new products. In conclusion, it remains to be seen whether the progress to be made in the near future optimizing the production, quality, and efficiency of cell division will be enough for artificial meat to be competitive in comparison to conventional meat and the increasing number of meat substitutes.

4. Recommendations for GASL action

Having explored successful cases that highlight practical solutions for dealing with key drivers' pressures on livestock systems, here we transition toward actionable recommendations. The knowledge and experience shared in the preceding sections offer a valuable foundation upon which GASL can build its strategies for action. These recommendations, rooted in real-world achievements, address critical aspects that demand our attention for the betterment of the livestock industry.

Some of the recommendations resulting from this series of webinars to tackle key drivers affecting the sustainability and resilience of livestock systems were as follows:

4.1 For environmental and technology innovation drivers

- Channel resources not only to mitigation but to adaptation as well, increasing system resilience and securing farmers' capital, assets, and livelihoods.
- Identify proxies for monitoring gains in biodiversity, mitigation, adaptation, and water-use efficiency when applying innovations at a large scale.
- Apply a holistic approach to evaluate competing claims of alternatives to livestock-based commodities.
- Improve the understanding of trade-offs and synergies between sustainable, climate-smart practices and socioeconomic benefits.
- Promote convergence between the various triggers of change in livestock value chains: incentives, conditioned credits, extension, and access to land, considering the comparative advantages of different livestock systems and their complementarity with other systems.
- Encourage the smart use of novel technologies like digitalization, big data, and genomics to enhance livestock production efficiency, disease control, and genetic improvements, among other applications.
- Influence the design of undergraduate and postgraduate curricula, continuous education programs for technicians, and farmers' extension activities to incorporate the impacts of environmental and technological innovations as a means to drive meaningful transformations in the sector.
- Advocate for collective action of diverse stakeholders in the livestock sector in seeking and implementing solutions through the establishment of knowledge-sharing platforms, policy incentives, and funding mechanisms to encourage joint initiatives, which will play a pivotal role in the sustainable progression of the livestock sector in an ever-changing world.

4.2 For health and disease drivers

- Focus on sustainable intensification of animal production systems, emphasizing animal welfare and reducing disease risks.
- Apply the One Health approach to integrate human, livestock, and environmental levels for preventing disease outbreaks and controlling or reducing their impacts.
- Promote responsible and informed use of antibiotics and other human health and veterinary products, targeting research, education, government institutions, private sector livestock enterprises, and consumers.
- Train veterinary service providers to use digital tools for effective health diagnosis and treatment at the field level.
- Share and use surveillance data to identify disease hotspots for improving decision-making in livestock and human health.
- Use clinical data to develop diagnostic tests and treatment strategies, leveraging genetic data for resistance to diseases and new biological veterinary products like vaccines.

- Equip veterinary laboratories with standardized methods and digital tools to expedite disease diagnosis, enhancing the delivery of veterinary and food safety services and guidelines for proper biosecurity measures.
- Conduct studies to assess the cost-effectiveness of different disease control measures.
- Promote collective action through private-public partnerships for addressing animal health concerns, covering diverse topics such as diagnostic technologies, vaccines, antibiotic alternatives, biosecurity measures, and socioeconomic impacts of diseases.

4.3 For geopolitical and socioeconomic drivers

- Analyze potential interventions to tackle geopolitical and socioeconomic challenges based on country differences.
- Forecast and share information on potential impacts of climate change, market price changes, local and global conditions, and political decisions for stakeholder decision-making.
- Examine the impact of financial institutions on the sustainable transformation of the livestock sector, focusing on interest rates, access to credits, and transaction costs, especially for medium and small investors.
- Promote local and foreign investments in livestock farming, feed production, processing, and other livestock value chain activities, emphasizing short- and long-term investments and political stability.
- Update data on the demand elasticity for livestock products in different countries and consider the effects of supply and demand shocks from different drivers.
- Understand which characteristics of livestock products are most valued by consumers in different countries and how they influence production changes.
- Conduct case studies in countries committed to carbon-neutral livestock systems to generate data on the feasibility of those strategies.
- Analyze current conditions and future trends in carbon credit prices for incentivizing farmers to reduce emissions and enhance carbon sequestration in livestock farms.
- Promote studies assessing the impact of meat and milk substitutes on diet quality, GHG emissions, and consumer willingness to adopt them based on cultural, religious, and economic factors.
- Share the results and lessons learned through the webinar series regarding the drivers of change affecting livestock systems, their impacts on sustainability and resilience, and potential solutions.

5. Final reflections

The comprehensive analysis of the drivers of change affecting livestock systems, conducted in this series of webinars organized by GASL and CATIE, reveals a complex and multifaceted picture of the challenges and opportunities facing the livestock sector worldwide. Through the exploration of drivers of environmental and technological innovation, health and diseases, and geopolitical and socioeconomic issues, a deeper understanding of the various factors impacting sustainability and resilience of these systems has been achieved.

The effects of urbanization and economic growth on the increased demand for animal-sourced foods, as well as the pressure on natural resources, have highlighted the need for innovative and sustainable solutions. To address the challenges posed by changes in climate and land use, a deeper understanding of their impacts on biodiversity, mitigation, adaptation, and water use efficiency is essential. Furthermore, the role of technology, digitization, and genomics in improving livestock production efficiency, disease control, and genetic improvement is becoming increasingly relevant with time.

Regarding health and diseases, the importance of adopting a comprehensive "One Health" approach, addressing challenges of zoonotic diseases, antimicrobial resistance, and efficient health data management, has been emphasized. Public-private collaboration and the promotion of responsible practices in the food supply chain are essential to reduce risks to human and animal health.

Geopolitical and socioeconomic drivers have revealed the complexity of regional and national dynamics, with a variety of factors affecting livestock production, from population growth and urbanization to consumer preferences and trade agreements. Recognizing the diversity of these dynamics and adapting solutions at the local level is crucial to addressing sustainability challenges.

Ultimately, the recommendations generated from these analyses provide valuable roadmaps for driving action within the framework of GASL. Promoting sustainable and climate-smart practices, multi-stakeholder collaboration, and investment in research and technology are critical steps to ensure that the livestock sector can meet future challenges.

This report highlights the need for a comprehensive and collaborative approach to address the challenges facing livestock systems worldwide. Sustainability and resilience are achievable goals, but they require ongoing commitment and coordinated actions. As we move towards an ever-changing future, it is imperative that stakeholders work together to ensure that the livestock sector can thrive sustainably and deliver benefits at the environmental, social, and economic levels.

This series of webinars has laid the groundwork for ongoing dialogue and collaborative action in the livestock sector. The reflections and recommendations presented here are expected to be a valuable resource for those seeking to address the challenges and opportunities facing the livestock sector in the 21st century. As we move towards a more sustainable and resilient future, it is crucial that we leverage the lessons learned and apply innovative solutions for dealing with drivers of change in livestock systems and ensure a promising future for the livestock industry.

This report summarizes the results of the series of webinars held on September 5-11, 2023, in preparation for the 13th GASL Multi-Stakeholder Partnership entitled "Multi-stakeholder collaboration to strengthen sustainability and resilience of livestock systems in response to drivers of change," held in Chiang Mai, Thailand, on October 30-November 3, 2023. There were also other regional consultations for China, East Europe, Latin America, West Europe, Oceania, and South Asia, whose reports are available on the GASL website (https://www.livestockdialogue.org). All of these are sources of valuable information to be disseminated to create consciousness on the need for transforming the livestock sector globally.

References

Abay, KA; Breisinger, C; Glauber, J; Kurdi, S; Laborde, D; Siddig, K. 2023. The Russia-Ukraine war: Implications for global and regional food security and potential policy responses. Global Food Security 36:100675. https://doi.org/10.1016/j.gfs.2023.100675

Allen, T; Murray, KA; Zambrana-Torrelio, C; Morse, SS; Rondinini, C; Di Marco, M; Breit, N; Olival, KJ; Daszak, P. 2017. Global hotspots and correlates of emerging zoonotic diseases. Nature Communications 8(1):1124. https://doi.org/10.1038/s41467-017-00923-8

Baltenweck, I; Enahoro, D; Frija, A; Tarawali, S. 2020. Why is production of animal source foods important for economic development in Africa and Asia? Animal Frontiers 10(4):22-29.

Belmin, RP; Malézieux, E. 2023. Adapting agriculture to climate change: which pathways behind policy initiatives? Agronomy for Sustainable Development 43: 59. https://doi.org/10.1007/s13593-023-00910-y

Bryant, C; Barnett, J. 2018. Consumer acceptance of cultured meat: A systematic review. Meat Science 143: 8-17. https://doi.org/10.1016/j.meatsci.2018.04.008

Burkart, S; Díaz, MF; Enciso, K; Charry, A; Triana-Ángel, N; Mena, M; Urrea-Benítez, JL; Gallo Caro, I; Van der Hoek, R. 2022. The impact of COVID-19 on the sustainable intensification of forage-based beef and dairy value chains in Colombia: a blessing and a curse. Tropical Grasslands-Forrajes Tropicales 10(3):237–248. https://doi.org/10.17138/TGFT(10)237-248

Burrell, A; Ferrari, E; Mellado, AG; Himics, M; Michalek, J; Shrestha, S; Van Doorslaer, B. 2011. Potential EU-Mercosur free trade agreement: impact assessment. Vol. 1. Main Results. EU Commission Joint Research Centre, Seville, Spain. 136 pp. ISBN 978-92-79-21806-4 (PDF).

Calle, Z; Murgueitio, E; Chará, J; Molina, CH; Zuluaga, AF; Calle A. 2013. A strategy for scaling-up intensive silvopastoral systems in Colombia. Journal of Sustainable Forestry 32: 677-693.

Casasola, F; Ibrahim, M; Ramírez, E; Villanueva, C; Sepúlveda, C; Araya, JL. 2007. Pagos por servicios ambientales y cambios en usos de la tierra en paisajes dominados por la ganadería en el trópico subhúmedo de Nicaragua y Costa Rica. Agroforestería en las Américas 45:79-85.

Chala, B; Hamde, F. 2021. Emerging and Re-emerging Vector-Borne Infectious Diseases and the Challenges for Control: A Review. Frontiers in Public Health 9:715759. https://doi.org/10.3389/fpubh.2021.715759

Chan, K; Millinger, M; Schneider, UA; Thrän, D. 2022. How diet portfolio shifts combined with land-based climate change mitigation strategies could reduce climate burdens in Germany. Journal of Cleaner Production 376:134200. https://doi.org/10.1016/j.jclepro.2022.134200

Chan, KH; Peiris, JS; Lam, SY; Poon, LL; Yuen, KY; Seto, WH. 2011. The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus. Advances in Virology 2011: 734690. https://doi.org/10.1155/2011/734690

Chriki, S; Hocquette, JF. 2020. The myth of cultured meat: a review. Frontiers in Nutrition. 7:7. https://doi.org/10.3389/fnut.2020.00007

Cole, RJ. 2010. Social and environmental impacts of payments for environmental services for agroforestry on small-scale farms in southern Costa Rica. International Journal of Sustainable Development & World Ecology 17: 208–216.

Dafale, NA; Srivastava, S; Purohit, HJ. 2020. Zoonosis: An Emerging Link to Antibiotic Resistance Under "One Health Approach." Indian Journal of Microbiology 60:139-152. https://doi.org/10.1007/s12088-020-00860-z

Dagang, ABK; Nair, PKR. 2003. Silvopastoral research and adoption in Central America: recent findings and recommendations for future directions. Agroforestry Systems 59: 149—155.

Daniels, AE; Bagstad, K; Esposito, V; Moulaert, A; Rodriguez, CM. 2010. Understanding the impacts of Costa Rica's PES: Are we asking the right questions? Ecological Economics 69: 2116–2126.

Delgado, C; Rosegrant, M; Steinfeld, H; Ehui, S; Courbois, C. 1999. Livestock to 2020: The next food revolution. IFPRI. Food, Agriculture, and the Environment Discussion Paper 28. IFPRI, Washington, D.C., USA. 72 pp.

Deniz, M; De-Sousa, KT; Vieira, FM; Vale, MM; Dittrich, JR; Daros, RR; Hötzel, MJ. 2023. A systematic review of the effects of silvopastoral system on thermal environment and dairy cows' behavioral and physiological responses. International Journal of Biometeorology 67(3):409-422.

Días-Filho, MB. 2007. Degradação de pastagens: Processos, causas e estratégias de recuperação. 3ra. Ed. EMBRAPA Amazonia Oriental, Belem, Brazil. 190 pp.

Dupraz, P. 2020. Policies for the ecological transition of agriculture: the livestock issue. Review of Agricultural, Food and Environmental Studies 101(4):529-538. https://doi.org/10.1007/s41130-020-00135-7

Enahoro, D; Bahta, S; Mensah, C; Oloo, S; Rich, KM. 2021. Current and future trade in livestock products. OIE Revue Scientifique et Technique 40(2):395-411. https://doi.org/10.20506/rst.40.2.3232

Enríquez-Quiroz, JF; Esqueda-Esquivel, VA; Martínez-Méndez, DM. 2021. Rehabilitation of degraded pastures in the tropics of Mexico. Revista Mexicana de Ciencias Pecuarias 12:243-260.

FAO/UNDP. 2017. Integrating Agriculture in National Adaptation Plans (NAP-Ag) Programme. Case Study: Uruguay. FAO, Rome, Italy. 15 pp.

Franco, JR; Cecchi, G; Paone, M; Diarra, A; Grout, L; Kadima Ebeja, A; Simarro, PP; Zhao, W; Argaw, D. 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS Neglected Tropical Diseases 16(1):e0010047. https://doi.org/10.1371/journal.pntd.0010047

García-Cruz, F; Ibrahim, M; Pezo, D. 2013. Los árboles en los potreros para la reducción del estrés calórico del ganado en los trópicos. In: D. Sánchez, C. Villanueva, G. Rusch, M. Ibrahim, F. DeClerck (eds.). Estado del recurso arbóreo en fincas ganaderas y su contribución en la producción en Rivas, Nicaragua. CATIE, Turrialba, Costa Rica. Pp. 36-41.

Goda, T. 2013. Changes in income inequality from a global perspective: an overview. Post Keynesian Economics Study Group Working Paper 1303. 35 pp.

Grace, D; Lindahl, J; Wanyoike, F; Bett, B; Randolph, T; Rich, KM. 2017. Poor livestock keepers: ecosystem–poverty–health interactions. Philosophical Transactions of the Royal Society B: Biological Sciences 372(1725):20160166. https://doi.org/10.1098/rstb.2016.0166

Grimm, NB; Faeth, SH; Golubiewski, NE; Redman, CL; Wu, J; Bai, X; Briggs, JM. 2008. Global change and the ecology of cities. Science 319(5864):756-760.

Gwaka, L; Dubihlela, J. 2020. The Resilience of Smallholder Livestock Farmers in Sub-Saharan Africa and the Risks Imbedded in Rural Livestock Systems. Agriculture 10(7):270. https://doi.org/10.3390/agriculture10070270

Halliday, JE; Allan, KJ; Ekwem, D; Cleaveland, S; Kazwala, RR; Crump, JA. 2015. Endemic zoonoses in the tropics: a public health problem hiding in plain sight. Veterinary Record 176(9): 220-225. https://doi.org/10.1136/vr.h798

Herrero, M; Gerber, P; Vellinga, T; Garnett, T; Leip, A; Opio, C; Westhoek, H; Thornton, PK; Olesen, J; Hutchings, N. 2011. Livestock and greenhouse gas emissions: The importance of getting the numbers right. Animal Feed Science and Technology 166:779-782.

Herrero, M; Mason-D'Croz, D; Thornton, PK; Fanzo, J; Rushton, J; Godde, C; Bellows, A; de Groot, A; Palmer, J; Chang, J; van Zanten, H. 2023. Livestock and sustainable food systems: Status, trends, and priority actions. In: Von Braun J; Afsana, K; Fresco, LO; Hassam, MHA (Ed.) Science and Innovations for Food Systems Transformation. Springer, Switzerland. Pp. 375-400. https://doi.org/10.1007/978-3-031-15703-5

Herrero, M; Thornton, PK. Livestock and global change: Emerging issues for sustainable food systems. 2013. Proceedings of the National Academy of Sciences 110(52):20878-20881. https://doi.org/10.1073/pnas.1321844111

Heyl, K; Ekardt, F; Roos, P; Stubenrauch, J; Garske, B. 2021. Free Trade, Environment, Agriculture, and Plurilateral Treaties: The Ambivalent Example of Mercosur, CETA, and the EU–Vietnam Free Trade Agreement. Sustainability 13(6):3153. https://doi.org/10.3390/su13063153

Huertas, SM; Bobadilla, PE; Alcántara, I; Akkermans, E; van Eerdenburg, FJ. 2021. Benefits of silvopastoral systems for keeping beef cattle. Animals 11(4):992. https://doi.org/10.3390/ani11040992

Hwang, J; You, J; Moon, J; Jeong, J. 2020. Factors affecting consumers' alternative meats buying intentions: Plant-based meat alternative and cultured meat. Sustainability 12(14):5662. https://doi.org/10.3390/su12145662

Ibidhi, R; Salem, HB. 2020. Water footprint of livestock products and production systems: A review. Animal Production Science 60(11):1369-1380.

Ibrahim, M; Porro, R; Martins, RM. 2010. Deforestation and livestock expansion in the Brazilian Legal Amazon and Costa Rica: Drivers, environmental degradation, and policies for sustainable land management. In: Steinfeld, H., Mooney, H.A., Schneider, F., Neville, L.E. (eds.) Livestock in a Changing Landscape. Vol. 2. Drivers, Consequences and Responses. Island Press, Washington, D.C., USA. Pp. 74-95.

Ibrahim, M; Villanueva, C: Casasola, F; Rojas, J. 2006. Sistemas silvopastoriles como una herramienta para el mejoramiento de la productividad y restauración de la integridad ecológica de paisajes ganaderos. Pastos y Forrajes (Cuba) 29: 383-419.

IPCC (Intergovernmental Panel on Climate Change, U.S.). 2006. Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Vol. 41, IGES, Japan. 49 pp. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Ismail, BP; Senaratne-Lenagala, L; Stube, A; Brackenridge, A. 2020. Protein demand: Review of plant and animal proteins used in alternative protein product development and production. Animal Frontiers 10(4):53-63.

Jones, BA; Grace, D; Kock, R; Alonso, S; Rushton, J; Said, MY; McKeever, D; Mutua, F; Young, J; McDermott, J; Pfeiffer, DU. 2013. Zoonosis emergence linked to agricultural intensification and environmental change. Proc. Natl. Acad. Sci. U. S. A. 110:8399–8404. https://doi.org/10.1073/pnas.1208059110

Kaimowitz, D. 1996. Livestock and deforestation in Central America in the 1980s and 1990s: A policy perspective. Center for International Forestry Research (CIFOR). Special Publication, Bogor, Indonesia. 88 pp.

Karesh, WB; Dobson, A; Lloyd-Smith, JO; Lubroth, J; Dixon, MA; Bennett, M; Aldrich, S; Harrington, T; Formenty, P; Loh, EH; Machalaba, CC; Thomas, MJ; Heymann, DL. 2012. Ecology of zoonoses: natural and unnatural histories. Lancet 380:1936–1945. http://dx.doi.org/10.1016/S0140-6736(12)61678-X

Kim, SW; Less, JF; Wang, L; Yan, T; Kiron, V; Kaushik, SJ; Lei, XG. 2019. Meeting Global Feed Protein Demand: Challenge, Opportunity, and Strategy. Annual Review of Animal Biosciences 7:221-243. https://doi.org/10.1146/annurev-animal-030117-014838

Komarek, AM; Dunston, S; Enahoro, D; Godfray, HC; Herrero, M; Mason-D'Croz, D; Rich, KM; Scarborough, P; Springmann, M; Sulser, TB; Wiebe, K. 2021. Income, consumer preferences, and the future of livestock-derived food demand. Global Environmental Change 70:102343.

Lee, R. 2011. The Outlook for Population Growth. Science 333(6042):569-573. https://www.science.org/doi/10.1126/science.1208859

Li, Y; Zhong, H; Shan, Y; Hang, Y; Wang, D; Zhou, Y; Hubacek, K. 2023. Changes in global food consumption increase GHG emissions despite efficiency gains along global supply chains. Nature Food 4:483–495. https://dx.doi.org/10.1038/s43016-023-00768-z

Ma, M; Wang, HH; Hua, Y; Qin, F; Yang, J. 2021. African swine fever in China: Impacts, responses, and policy implications. Food Policy 102:102065.

Mackey, TK; Liang, BA; Cuomo, R; Hafen, R; Brouwer, KC; Lee, DE. 2014. Emerging and reemerging neglected tropical diseases: a review of key characteristics, risk factors, and the policy and innovation environment. Clinical Microbiology Reviews 27(4):949-79.

MAG-Costa Rica. 2015. Estrategia 2015 - 2034 y Plan de Acción para la Ganadería Baja en Carbono en Costa Rica. Ministerio de Agricultura y Ganadería (MAG) y Ministerio de Ambiente y Energía (MINAE), San José, Costa Rica. 13 pp.

McDermott, JJ; Staal, SJ; Freeman, HA; Herrero, M; Van de Steeg, JA. 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livestock Science 130(1-3):95-109.

McSweeney, K; Richani, N; Pearson, Z; Devine, J; Wrathall, DJ. 2017. Why do narcos invest in rural land? Journal of Latin American Geography 1:3-29.

Murgueitio, E; Calle, Z; Uribe, F; Calle, A; Solorio, B. 2011. Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. Forest Ecology and Management 261: 1654—1663.

Nkonki-Mandleni, B; Ogunkoya, FT; Omotayo, AO. 2019. Socioeconomic factors influencing livestock production among smallholder farmers in the

free state province of south Africa. International Journal of Entrepreneurship 23(1):1-7.

Nnko, HJ; Gwakisa, PS; Ngonyoka, A; Sindato, C; Estes, AB. 2021. Potential impacts of climate change on geographical distribution of three primary vectors of African Trypanosomiasis in Tanzania's Maasai Steppe: G. m. morsitans, G. pallidipes and G. swynnertoni. PLoS Neglected Tropical Diseases 15(2):e0009081. https://doi.org/10.1371/journal.pntd.0009081

Pagiola, S; Agostini, P; Gobbi, J; de Haan, C; Ibrahim, M; Murgueitio, E; Ramírez, E; Rosales, M; Ruíz, JP. 2005. Paying for biodiversity conservation services. Mountain Research and Development 25(3):206-211.

Parlasca, MC; Qaim, M. 2022. Meat Consumption and Sustainability. Annual Review of Resource Economics 14:17-41. https://doi.org/10.1146/annurev-resource-111820-032340

Parra, AS; Ramirez, DY; Martínez, EA. 2022. Silvopastoral Systems Ecological Strategy for Decreases C Footprint in Livestock Systems of Piedmont (Meta), Colombia. Brazilian Archives of Biology and Technology 66. https://doi.org/10.1590/1678-4324-2023220340

Perry, BD; 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. https://doi.org/10.1073/pnas.1012953108

Peters, M; Rao, I; Fisher, M; Subbarao, G; Martens, S; Herrero, M; Hoek, R; van der Schultze-Kraft, R; Miles, J; Castro, A; Graefe, S; Tiemann, T; Ayarza, M; Hyman, G. 2013. Tropical forage-based systems to mitigate greenhouse gas emissions. In: Hershey, C.H.; Neate, P. (eds.). Eco-efficiency: From vision to reality. CIAT Publication No. 381. CIAT, Cali, Colombia. Pp. 171–190.

Pezo, D; Ríos, N; Ibrahim, M; Gómez, M. 2018. Silvopastoral Systems for Intensifying Cattle Production and Enhancing Forest Cover: The Case of Costa Rica. LEAVES, Background Paper. PROFOR. World Bank, Washington, D.C., USA. 76 pp.

Rasch, S; Wünscher, T; Casasola, F; Ibrahim, M; Storm, H. 2021. Permanence of PES and the role of social context in the Regional Integrated Silvo-pastoral Ecosystem Management Project in Costa Rica. Ecological Economics 185:107027.

Revell, B. Meat and Milk Consumption 2050: the Potential for Demand-side Solutions to Greenhouse Gas Emissions Reduction. 2015. EuroChoices 14(3):4-11. https://doi.org/10.1111/1746-692X.12103

Revell, BJ. 2015. One Man's Meat… 2050? Ruminations on future meat demand in the context of global warming. Journal of Agricultural Economics 66(3):573-614.

Rivera-Céspedes, M; Méndez, JB; Guindon, L; Méndez, E; Pezo, D. 2016. Hacia una ganadería productiva y amigable con el ambiente en Hojancha, Costa Rica. In: H.H. Li Pun et al. (eds.). Innovaciones de Impacto: Lecciones sobre Adaptación al Cambio Climático de la Agricultura Familiar en América Latina y el Caribe. BID-FONTAGRO. Washington, D.C., USA. Pp. 67-75.

Roebeling, PC; Hendrix, EMT. 2010. Land speculation and interest rate subsidies as a cause of deforestation: The role of cattle ranching in Costa Rica. Land Use Policy 27: 489–496.

Rojas-Downing, MM; Nejadhashemi, AP; Harrigan, T; Woznicki, SA. 2017. Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management 16:145-163. http://dx.doi.org/10.1016/j.crm.2017.02.001

Rose, S; Khatri-Chhetri, A; Stier, M; Wilkes, A; Shelton, SW; Arndt, C; Wollenberg, EK. 2021. Livestock Management Ambition in the New and Updated Nationally Determined Contributions: 2020-2021: Analysis of Agricultural Sub-Sectors in National Climate Change Strategies. https://cgspace.cgiar.org/handle/10568/115885

Scholten, MT; De Boer, IJ; Gremmen, B; Lokhorst, C. 2013. Livestock farming with care: towards sustainable production of animal-source food. Wageningen Journal of Life Sciences 66(1):3-5.

Selvaraju, R. 2012. Climate risk assessment and management in agriculture. In: Meybeck A; Lankoski J; Redfern S; Azzu N; Gitz V. (eds). Building resilience for adaptation to climate change in the agriculture sector. Proceedings of a Joint FAO/OECD Workshop. FAO, Rome. Pp. 71-90.

Shimada, J; Nepstad, D. 2018. Beef in the Brazilian Amazon. Leveraging Agricultural Value Chains to Enhance Tropical Tree Cover and Slow Deforestation (LEAVES). Background Paper. PROFOR and World Bank, Washington, D.C., USA. 4 pp.

Sibly, RM; Hone, J. 2002. Population growth rate and its determinants: an overview. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences 357(1425):1153-1170.

Smith, JW; Opio, C; Steinfeld, H; Lufafa, A. 2010. Global demand and trade in livestock and livestock products in a globalizing world. In: Estany J; Nogareda C.; Rothschild M. (eds). Adapting Animal Production to Changes for a Growing Human Population. University of Lleida, Spain. Pp. 25-34.

Solorio, SFJ; Wright, J; Franco, MJA; Basu, SK; Sarabia, SL; Ramírez, L; Ayala, BA; Aguilar, PC; Ku-Vera, JC. 2017. Silvopastoral systems: Best agroecological practice for resilient production systems under dryland and drought conditions. In: Ahmed, M; Stockle, C (eds.) Quantification of Climate Variability, Adaptation and Mitigation for Agricultural Sustainability. Springer, Heidelberg, Germany. Pp. 233-250.

Steinfeld, H; Gerber, P; Wassenaar, T; Castel, V; Rosales, M; de Haan, C. 2006. Livestock's long shadow: environmental issues and options. Rome, Italy, FAO. 392 pp.

Thornton, PK; van de Steeg, J; Notenbaert, A; Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agricultural Systems 101(3):113-127.

Trilleras, JM; Jaramillo, VJ; Vega, EV; Balvanera, P. 2015. Effects of livestock management on the supply of ecosystem services in pastures in a tropical dry region of western Mexico. Agriculture, Ecosystems and Environment 211: 133-144.

Tuomisto, HL. 2019. The eco-friendly burger: could cultured meat improve the environmental sustainability of meat products? EMBO Reports. 20(1): e47395. DOI 10.15252/embr.201847395.

UNEP and ILRI. 2021. Preventing the next pandemic: zoonotic diseases and how to break the chain of transmission. A Special Volume of UNEP's Frontiers Report Series. Nairobi, Kenya. 72 pp.

Villanueva, C; Ibrahim, C; Hänsen, G. 2010. Producción y rentabilidad de sistemas silvopastoriles: Estudios de caso en América Central. CATIE, Serie Técnica, Manual Técnico no. 95. CATIE, Turrialba, Costa Rica. 78 pp.

Villanueva, C; Moscoso, C; Detlefsen, G; Solis, J; López, J. 2023. Contribution of tree cover to the compensation of greenhouse gas emissions from dairy farms in the southeast of Guatemala. Latin American Archives of Animal Production 31(1):93-102. https://doi.org/10.53588/alpa.310105

Wattiaux, MA; Iñamagua-Uyaguari, JP; Alarcón-Guerra, LG; Casasola-Coto, F; Jenet, A. 2016, Feeding and fertilization practices and greenhouse gas emissions in specialized dairy farms of Dos Pinos in Costa Rica. Tropical Grasslands-Forrajes Tropicales 4(3):146–158. https://doi.org/10.17138/tgft(4)146-158

Zaremba, A; Aharon, DY; Demir, E; Kizys, R; Zawadka, D. 2021. COVID-19, government policy responses, and stock market liquidity around the world: A note. Research in International Business and Finance. 56:101359. https://doi.org/10.1016/j.ribaf.2020.101359

Zbinden, S; Lee, DR. 2005. Paying for Environmental Services: An Analysis of Participation in Costa Rica's PSA Program. World Development 33: 255–272. https://doi.org/10.1016/j.worlddev.2004.07.012

ANNEX 1

WEBINAR 1

ENVIRONMENTAL AND TECHNOLOGICAL INNOVATION DRIVERS

1. General information

Webinar Title: Environmental and Technological Innovation Drivers

Date: September 5, 2023

Moderator/Facilitator:
Mariel Merayo, LLM / Danilo Pezo, Ph.D

Coordination:
Astrid Pulido, Ph.D / Ileana Avalos, Ph.D

Panelists/Speakers:

Welcome Address
- Shirley Tarawali, Chair, GASL (Global Agenda for Sustainable Livestock)
- Muhammad Ibrahim, Director General, CATIE

Introduction
Henning Steinfeld, Consultant, GASL

Status of environmental drivers of change in livestock systems
Keynote speaker:
Muhammad Ibrahim, Director General, CATIE

Solutions to address the pressures of environmental drivers
Panelists
- Pierre Gerber, Senior Livestock Specialist, World Bank
- Aditi Mukerji, Climate Adaptation and Mitigation Impact Area Platform
- Juan Jaramillo, Technical Support Unit, Mitigation Action Facility

Solutions to address the pressures of innovation technological drivers
Panelists
- Daniel Mason-D'Croz, Senior Research Associate, Cornell Global Development, Cornell University
- Alison Van Eenennaam, Department of Animal Science, University of California

Number of participants: 158

2. Event summary

The world is undergoing significant transformations brought about by many factors such as demographics, the climate crisis, the COVID-19 pandemic, geopolitical tensions, and advancements in technology. These shifts have had a profound impact on various aspects of our lives, including livestock systems. To address these changes and ensure a sustainable future, it is crucial to develop a comprehensive agri-food systems strategy that encompasses the entire value chain from resources to consumption. This strategy should also emphasize the importance of digitalization and modern technologies in livestock agriculture.

Global change is occurring at an unprecedented rate, exemplified by crises like pandemics, geopolitical conflicts, extreme weather events, and economic challenges. These elements have instilled a sense of volatility and the potential for major disruptions. To navigate these uncertainties, taking an integrated approach to agri-food systems is essential. This approach should focus on the entire livestock system and recognize the transformative role of digitalization, robotics, big data, and genomic breakthroughs in livestock agriculture. It is also important to acknowledge the emergence of alternative sources of livestock products.

One notable issue that deserves attention is the surge in meat production, especially in the Amazon, and its connection to deforestation. To address this concern, we need to emphasize the significance of digitalization and the adoption of eco-friendly technologies. Additionally, discussions should revolve around the impact of climate change on water resources and its implications for livestock agriculture.

This presentation also highlighted the challenges posed by climate change, such as glacier effects and water shortages. It addresses issues like heat stress, which negatively affects livestock productivity due to climate change. It is essential to consider mitigation techniques and the interplay between climate change and social equity in addressing these challenges.

The pivotal role of innovation and technology in agri-food systems is a crucial topic, particularly considering the projected persistence of meat demand, the growing interest in alternative proteins, and the importance of genetics in enhancing livestock yields. All of these factors call for the integration of technologies like artificial insemination, and also highlight the need for agricultural outreach and public investment.

In conclusion, it is crucial to adopt a comprehensive and interdisciplinary strategy to address the challenges and opportunities in livestock systems amidst rapid global transitions. By focusing on the entire system, embracing digitalization and modern technologies, and considering the impact of climate change and genetic advancements, we can ensure a sustainable and resilient future for livestock agriculture.

2.1 Environmental and technological innovation drivers

We are currently experiencing an era of unprecedented change, characterized by factors such as population growth, rapid urbanization, and increasing incomes. These dynamics, along with the climate crisis and the COVID-19 pandemic, are fundamentally transforming the global landscape, bringing about both challenges and opportunities across various sectors. The livestock sector is particularly affected, and it is important to consider the following drivers and specific aspects.

- **Population growth and urbanization:** The increasing number of individuals in the population has led to the conversion of rural areas into urban environments, a process known as urbanization. This phenomenon, combined with economic growth, has resulted in higher incomes and altered consumption patterns, including increased demand for animal source proteins.

- **Environmental and health impact of livestock:** While livestock plays a crucial role in meeting the protein demands of a growing population, it also has adverse effects on the environment and human health. Unsustainable livestock practices contribute to deforestation, land degradation, water scarcity, and biodiversity loss. Additionally, livestock has been linked to zoonotic diseases, with ecosystem degradation worsening the emergence and spread of these diseases.

- **Climate crisis, climate change, and carbon solutions:** Drastic shifts in global climate, worsened by human activities like deforestation and greenhouse gas emissions, are leading to ever more extreme weather events. These events, along with heat stress and variability in temperature and humidity indices, directly affect livestock production and management. In response, carbon offsets and carbon sequestration have appeared as mechanisms to reduce and store atmospheric carbon. However, it is important to ensure that climate actions are fair for all communities, particularly the most vulnerable.

- **Technological advances in livestock:** To address the challenges associated with livestock, advanced technologies have appeared. Digitalization, the use of big data, and genomics are tools aimed at optimizing production, reducing environmental impact, and enhancing livestock health. Genetic improvement, for example, involves the application of genetic and genomic techniques to enhance desirable traits in livestock. Digitalization and big data enable more efficient resource management.

- **Alternatives and sustainable solutions:** Given the rising demand for meat and its environmental impacts, alternatives to traditional livestock products, such as plant-based or lab-produced proteins, have been developed. Furthermore, promoting sustainable livestock management practices, improved pastures, and optimized production through supplementation are important strategies. Knowledge transfer and agricultural extension services play a crucial role in disseminating these practices.

- **Geopolitical and socioeconomic challenges:** In addition to environmental and technological challenges, the world faces geopolitical tensions that have implications for trade and food security. Climate equity and justice have become central themes, acknowledging the need for inclusive and fair solutions that benefit all communities.

In summary, in the Anthropocene era, where human activities have a considerable influence on climate and the environment, it is essential to adopt a "One Health" approach that recognizes the interconnections between the health of the planet, people, and ecosystems. As we approach planetary boundaries, collaboration, innovation, and the convergence of sectors will be key to ensuring a sustainable and resilient future.

2.2 Drivers' impact

The effects of various drivers on livestock systems, and vice versa, have been examined and are outlined below.

- **Livestock transformations:** Transformations in livestock systems not only represent a key driver in global supply chains and the economy, but they are also undergoing profound changes due to multiple influences and factors. These shifts are redefining livestock farming practices, from animal rearing and feeding to the marketing and consumption of livestock products.

- **Drivers of change in livestock systems:** The growing demand for animal products is clear, but it also raises concerns about the environmental and health impacts of intensive livestock production. Factors such as resource scarcity, climate change, and disease outbreaks are exerting pressures on livestock farming. For example, competition for land and water can increase production expenses, while diseases can lead to market shutdowns and economic setbacks.

- **Innovation and technology:** the cornerstones of sustainable livestock production: Embracing innovative technologies and methodologies is crucial for the transformation of livestock farming. Digitalization and the use of big data, for instance, are helping to enhance the efficiency and sustainability of the sector.

  These driving factors highlight the importance of adopting environmentally conscious, health-promoting, and sustainable livestock practices. While challenges like deforestation and climate change pose significant obstacles to livestock farming, opportunities like digitalization can improve efficiency and sustainability.

- **Towards resilient and sustainable livestock production:** Practices such as water efficiency, the restoration of degraded grasslands, and carbon sequestration in grasslands can enhance production while reducing emissions. Moreover, carbon offsetting appears as a powerful strategy to mitigate the environmental footprint of livestock farming. Conversely, genetic enhancements and supplementation can boost livestock

productivity and adaptability to changing circumstances. Taking a comprehensive, evidence-driven approach is crucial to progress towards sustainability in the livestock sector. Behavioral adaptations, pasture management, resource efficiency, and the integration of renewable energy are imperative to ensure the effectiveness of policies and practices, leading to intended results.

- **Collaboration and adaptability:** In the livestock sector, collaboration and adaptability are paramount. While high-level commitments such as the targets set by the Paris Agreement supply guidance, it is crucial to translate these commitments into tangible actions. The diverse nature of livestock systems suggests a variety of solutions and strategies that can be adapted based on local requirements and conditions.

In summary, livestock farming stands at a crossroads. Contemporary challenges demand innovative and collaborative solutions. A combination of innovative technologies, sustainable methodologies, and shifts in consumer behavior can supply a comprehensive approach to address the future challenges of sustainable livestock production.

2.3 Existing solutions

During the webinar, a wide range of solutions related to the discussed drivers were presented, addressing important topics such as innovative technologies, equity, and climate justice.

- **Technology and digitalization:** Innovative technologies are playing a crucial role in transforming various sectors, including livestock. Digitalization, along with the use of big data and genomics, is enabling enhanced production efficiency, prediction of livestock diseases, and genetic improvements that promote disease resistance and optimize production.

- **Sustainable resource management:** Given the challenges of resource scarcity and soil degradation, the adoption of sustainable practices is paramount. This includes improving pasture management systems, implementing efficient irrigation systems, and promoting water-use efficiency to ensure responsible resource management.

- **Climate mitigation and carbon:** Practical solutions like carbon sequestration and carbon offsets have appeared to reduce greenhouse gas emissions. By combining

these practices with the adoption of renewable energy sources, farms can become more sustainable and resilient in the face of climate change.

- **Biodiversity and conservation:** Preserving biodiversity is vital for keeping ecological balance. Deforestation, partly driven by the expansion of livestock production, needs to be counteracted with trade policies and practices that prioritize sustainability and forest conservation.

- **Equity and climate justice:** It is crucial to recognize that the impacts of climate change are not evenly distributed. Vulnerable communities often endure the most of these impacts, underscoring the need for policies that advocate for equity and climate justice.

These solutions supply a comprehensive approach to address the challenges presented by the drivers affecting the livestock sector. By embracing technology, sustainable resource management, climate mitigation, biodiversity conservation, and a commitment to equity and climate justice, we can work towards a more sustainable and resilient future for livestock agriculture.

2.4 The role of the multi-stakeholder approach

In the webinar, experts emphasized the pivotal role of collaboration among diverse stakeholders in effectively implementing solutions. They cited many successful initiatives where such collaboration has yielded positive outcomes. For instance, in the context of climate change mitigation, governments, NGOs (Non-Governmental Organization), the private sector, and academia have joined forces to promote sustainable livestock practices. One noteworthy example is the partnership between a leading agricultural university and a private agribusiness company to develop and disseminate eco-friendly farming techniques, reducing the carbon footprint of livestock operations. In the webinar, recommendations were put forth to further enhance collaboration among stakeholders, including the establishment of knowledge-sharing platforms, policy incentives, and funding mechanisms to encourage joint initiatives. These insights underscored the consensus that addressing livestock production challenges comprehensively requires a united effort across various sectors, ultimately ensuring a sustainable future for the industry.

2.5 Closing remarks

Throughout the panel discussion, the significance of tackling livestock production challenges from various perspectives was underscored. Key factors, including genetic enhancement, production intensification, the embrace of innovative technologies, and shifts in diet, are pivotal in deciding the trajectory of livestock production.

The webinar's first segment delved into environmental drivers, spotlighting the primary obstacles confronting livestock systems, with particular emphasis on the Anthropocene era and planetary boundaries. The "One Health" approach was introduced, underscoring the intricate link between the well-being of the planet, its inhabitants, and ecosystems.

The topic of diet and consumption was broached, drawing insights from the EAT-Lancet report. This segment explored the nexus between healthy diets and planetary boundaries, after steering the conversation towards meat and milk consumption. In this context, the surge in meat production, especially in the Amazon, and its correlation with deforestation was examined. The discourse accentuated the

imperative for sustainable trade policies to address challenges in the Livestock Sector.

Climate change, as a determinant, exerts profound effects on water resources, influencing both livestock and food production. The discourse emphasized the significance of formulating policies for sustainable water management within livestock systems. Additionally, the repercussions of climate change on livestock-induced heat stress and the value of climate mitigation technologies were explored.

Regarding carbon neutrality, the dialogue highlighted the potential of carbon sequestration in enhanced pastures and lauded the initiatives of organizations like CATIE in curbing emissions. The conversation underscored the necessity to understand the synergies between sustainable practices and their socio-economic dividends.

In the webinar's later segment, the pivotal role of innovations and technologies in agri-food systems was spotlighted. As global population numbers swell, a surge in demand for agricultural produce and meat is expected. In this backdrop, alternative proteins are posited as potential significant changes, though they aren't projected to wholly supplant traditional meat sources.

Furthermore, the intricate relationship between livestock and their environment was emphasized, with a focus on the role of genetics in augmenting livestock productivity. The successful implementation of technologies, exemplified by the adoption of artificial insemination in India, was highlighted. However, the scope for enhancing efficiency in livestock production stays vast. A salient point raised during the panel discussion was whether the intensification of livestock production, helped by advanced technologies, would suffice to cater to the escalating food demand. The consensus was that an integrated strategy, melding technological innovation with shifts in consumer patterns, is indispensable for navigating impending challenges in the agri-food domain.

Key points of concluding remarks

The educational perspective: The urgent need for education in livestock and environmental management is highlighted, with a focus on the critical question of whether university and postgraduate curricula are adequately addressing these issues. The discussion delves into the necessity of overhauling the education of professionals, technicians, and farmers to drive meaningful transformations in the sector. This viewpoint is supported by references to sustainable livestock production programs at leading institutions.

The connection between consumption and climate change: A complementary perspective emphasizes the importance of a comprehensive understanding of climate change. It draws attention to the link between individual behavior, especially consumption habits, and their impact on climate change. While climate change is a frequent topic in media discussions, the connection between personal choices and their global consequences may not always be apparent to the public. The need for empathy toward those directly affected by climate change, including small-scale producers and farmers, is also stressed.

Mainstreaming local knowledge and systems diversity: The discussion underscores the significance of local wisdom, particularly from indigenous communities, in areas such as climate change, agroforestry, and agroecology. It is emphasized that systems tailored to local conditions demonstrate greater resilience against climate change. Additionally, the conversation highlights the importance of recognizing the diversity of livestock systems and the urgency of rejuvenating soil health, while avoiding broad generalizations.

Definition and impact of livestock drivers: Identified drivers, including education, professional training, and climate change awareness, exert a direct influence on livestock practices. Education and training are crucial for adopting more sustainable and resilient methodologies. Understanding and adapting to climate change, altering consumption behaviors, and integrating local knowledge are seen as personalized and effective solutions to the sector's challenges.

Concluding remarks: The synthesis of expert insights underscores the need to address livestock production challenges from diverse perspectives. A combination of innovative technologies, shifts in consumer behavior, and well-considered policies can provide a comprehensive solution to the future challenges of livestock production. It is imperative for all stakeholders, including educators, farmers, and consumers, to collaborate in ensuring a sustainable future for livestock in the face of climate change.

ANNEX 2

WEBINAR 2

HEALTH AND DISEASE DRIVERS

1. General information

Webinar Title: Health and Disease Drivers

Date: September 7, 2023

Moderator/Facilitator:
Mariel Merayo, LLM / Danilo Pezo, Ph.D

Coordination:
Cristobal Villanueva, Ph.D. / Ileana Avalos, Ph.D

Panelists/Speakers:

Welcome Address

- Shirley Tarawali, Chair, GASL (Global Agenda for Sustainable Livestock)
- Muhammad Ibrahim, Director General, CATIE

Introduction
Henning Steinfeld, Consultant, GASL

Keynote Speaker
Luis Barcos

Panelists

- Keith Sumption, Chief Veterinary Officer, FAO
- Bernard Bett, Senior scientist, animal and human health, ILRI (International Livestock Research Institute)
- Hernan Villalobos, Corporate Manager of Climate Change and Renewable Energies, Arcos Dorados.
- Alex Rinkus, Director of communication and stakeholders' engagement, Health for Animals (Pharmaceutical Industry)
- Johnathan Rushton, Professor of Animal Health and Food Systems Economics, University of Liverpool.

Number of participants: 109

2. Event summary

During the webinar on health and disease drivers, the discussion primarily focused on the socioeconomic impacts of emerging diseases in pigs and poultry worldwide. Additionally, attention was paid to the improper use of antibiotics and dewormers in livestock, highlighting the associated risks to public health, production costs, and market implications. The session also addressed the relationship between drivers of intensification, trade, climate change, and livestock production systems and their impact on the overall landscape. For instance, severe droughts in various parts of the world have prompted the introduction or increased population of other species with better functional adaptation traits. Similarly, other factors such as pandemic threats, antibiotic resistance, promoting One Health, market dynamics, and available data for making informed decisions were given consideration.

It is vital to recognize that the health of livestock is intrinsically connected to the well-being of families, national economies, human health, and the environment. Therefore, collaborative actions at the local, national, and global levels are imperative to control and eradicate diseases and promote good health practices in livestock. Taking a holistic approach is necessary to comprehend the societal implications, biodiversity considerations, as well as adaptation and mitigation strategies related to climate change in livestock production. Additionally, the implementation of traceability systems in countries is crucial to enhance consumer confidence in the market.

Furthermore, effective collaboration between public and private entities is vital in managing knowledge, regulations, policies, certifications for markets, veterinary services, laboratories, and other stakeholders involved in ensuring the better health of livestock. These collaborative efforts translate into the sustainability and resilience of agrifood systems worldwide.

3. Health and disease drivers

Table 1 presents a comprehensive summary of the drivers, accompanied by illustrative examples, and provides insights into their potential impacts.

Table 1. Summary of drivers mentioned in the presentations

Drivers	Example	Operational impact
Intensification	Improved productivity and market orientation	Marginalization of smallholder/pastoral systems
Pandemic threats	COVID-19 and risk of new zoonotic diseases	Impact on the livelihoods of 1 in 5 people in developing countries
Antimicrobial resistance	Withdrawal and dosage dates are not respected	Access to market and public health risk, importance of traceability
Promoting One Health	A better balance among human, animal, and environmental health	More scientific evidence is needed and the relationship with sustainability and resilience, education of consumers around this approach; include this in regulations and policies
Climate change	Heat stress, loss of adaptation, health	Reduce animal production, family incomes and use new species in the landscape
Globalization and livestock trade	Traceability and stricter regulatory frameworks	A risk of promoting informal trade
Market (consumers)	Sustainable products	Developing value chain, demand of traceability; not all farmers or other actors in the supply chain have access to technology and lab services
Data available for better decision-making	Analysis to determine the relationship of diseases with production and income	Prevention of economic impact and on animal and human health

3.1 Drivers' impact

- **Intensification:** The risks associated with industrial production vs. extensive production, particularly in relation to species such as pigs and poultry, were discussed. Highlighted examples include the intensification trajectories observed in regions like Australia, New Zealand, North America, and Europe. For instance, the occurrence of African swine fever in China resulted in a contraction of the sow population by 34%, a notable change in live pig prices (+88% nationally), and an increase in the inter-provincial live pig price gap (+46%).

- **Pandemic threats:** The consequences of Covid-19 and the ongoing threat of new zoonotic diseases were emphasized. It is crucial to consider the following factors in this context: each year, 5% of new human diseases emerge, three of which originate from animals; 65% of human infectious diseases are zoonotic in nature; at least 75% of emerging human infectious diseases stem from animals; and 80% of potential bioterrorism pathogens are zoonotic.

- **Antimicrobial resistance:** The misuse of drugs and the use of substandard products have led to the emergence and spread of antimicrobial resistance, resulting in significant socioeconomic consequences. Disturbing situations have arisen, such as the practice of farmers mixing agricultural pesticides/veterinary drugs on their animals, which can have harmful effects on the animals and pose a public health hazard if these substances find their way into animal products. Examples mentioned include the use of acaricides to control ticks in cattle in developing countries, Denmark's program to reduce antibiotic use in pig production, and the need for more antibiotics in the Dutch broiler industry due to fast-growing breed types.

- **Promoting One Health:** The concept of One Health, which emphasizes integrated work at the human, livestock, and environmental levels, was discussed by speakers from organizations including WOAH (World Organization for Animal Health), FAO, and ILRI. While no case studies were presented, each pillar of the One Health approach was addressed individually. For example, the impact of poultry diseases on global hunger was highlighted (a 5% increase in 2019), and the environmental aspect was discussed in terms of how cattle diseases can increase greenhouse gas emissions.

- **Climate change:** Climate parameters, such as precipitation, temperature, and relative humidity, have influenced the prevalence of disease vectors and pests. Consequently, altering the equilibrium of production systems, animal welfare, and public health necessitates adopting control strategies and production systems to address these impacts. An example discussed was African trypanosomiasis, caused by the tsetse fly, which leads to a loss of $5 billion in GDP, poses a risk to 56 million cattle and 57 million people, and can be lethal. However, some countries including Kenya and Senegal have made progress in controlling or eliminating trypanosomiasis.

- **Globalization and livestock trade:** Globalization and livestock trade are interconnected, facilitating the global trade of livestock products, and increasing meat and dairy production and consumption. This has been influenced by factors such as the reduction of trade barriers and tariffs, improved transportation and storage technologies, and increased demand. While

global trade brings positive efficiency and productivity benefits, such as greater availability, quality, and lower costs of food, it also carries negative implications, including the spread of animal diseases, environmental degradation, and greenhouse gas emissions.

- **Market (consumers):** Restaurant chains offering sustainably produced animal-based food products are driving changes to expand sustainable livestock production. In the Latin American region, for example, there is an initiative where 100% of protein suppliers are audited by the AHW program, in accordance with the PAACO standard (Professional Animal Auditor Certification). Dairy ingredients are produced by suppliers who adhere to animal care and wholesome milk standards, and commitments have been made to a supply chain of 100% cage-free eggs by 2025.

- **Data available for better** decision-making: The effective use of data to improve decision-making in livestock health and disease is a complex task. However, utilizing data can enhance livestock health, productivity, and the prevention of disease outbreaks, protecting human health. There are various data sources that can be leveraged to make informed decisions in livestock health and disease management. By integrating data from these diverse sources, a more comprehensive understanding of the livestock health landscape can be achieved. This information can then be utilized to make informed decisions regarding disease prevention, control, and treatment. Several specific examples demonstrate how data can enhance decision-making in livestock health.

- **Surveillance data:** Effective utilization of surveillance data can identify high-risk areas for disease occurrence, enabling targeted control measures to be implemented more efficiently.

- **Clinical data:** The analysis of clinical data can contribute to the development of new diagnostic tests and treatment strategies for diseases. However, it is important to note that data availability, quality, and cost can be limiting factors in some countries.

- **Genetic data:** Leveraging genetic data can help identify animals that are susceptible to specific diseases, enabling preventive measures to be taken proactively.

- **Environmental data:** Analyzing environmental data can reveal factors that contribute to disease spread. This knowledge can guide efforts to mitigate those factors effectively. For instance, zoonotic diseases cause an annual toll of 2.2 million human deaths.

- **Economic data:** Assessing the cost-effectiveness of different control measures using economic data aids decision-making. Such analysis helps prioritize the implementation of specific measures. For example, the outbreak of African swine fever in 2019 resulted in an economic impact of $112.5 billion. In the case of cattle parasites in Brazil, it represents a cost of approximately $14 billion annually. By harnessing the power of data, livestock health management can be significantly enhanced, resulting in more effective disease control and mitigation efforts.

Existing solutions

Driver	Solution to mitigate negative effects	Successful program / project related to sustainability and resilience in livestock systems
Intensification	Digital tools to enhance service delivery and biosecurity measures.	
Pandemic threats	Biosecurity practices	PMP – TAB, poultry value chain Vietnam HPAI (Highly Pathogenic Avian Influenza)
Antimicrobial resistance	Educations, awareness, traceability	Denmark's Antibiotic Reduction Program
One Health	Investing in climate change adaptation and mitigation; promoting sustainable land use practices; better management of livestock operation; combating the illegal wildlife trade; strengthening global health surveillance and response systems	ILRI has some programs and projects
Climate Change	Drought-resistant breeds – goats, sheep, and camels – become the dominant species in pastoral systems	
Globalization and livestock trade	Traceability equivalence, zoning, and compartmentalization	
Market (consumers)	Diversification, differentiation, hedging, and innovation	Arcos Dorados: Recipe for the future
Data available for better decision-making	Telematic devices, fleet management software, and data analytic tools	Programs/tools of FAO

3.2 he role of the multi-stakeholder approach

There is significant interest among participating stakeholders, many of whom possess valuable expertise, in offering solutions to address healthcare and disease-related challenges. One noteworthy example is the enhancement of laboratory services and methodologies to elevate their quality. Additionally, the quest for improved access to laboratory services underscores the significance of cost-effective approaches. The subsequent paragraphs illustrate collaborative efforts involving various actors along the supply chain.

- **Global Burden of Disease (GBD):** GBD's primary focus revolves around evaluating past animal health policies and projects, enhancing baselines for future investment assessments, and creating a more comprehensive mapping of animal health investments aligned with sustainable development goals. GBD is actively engaged in case study activities encompassing livestock populations, the animal health loss envelope, attrition by disease, as well as health problems and accidents. This initiative collaborates closely with government and private sector stakeholders in Ethiopia, Indonesia, the UK, and the EU, with expansion efforts underway in Australia, the Americas, and Senegal.

- **Health for Animals:** Health for Animals collaborates with 50 countries, over 29 regional and national organizations, and partners with 10 major healthcare companies spanning more than 100 countries. The central theme of this collaboration revolves around health and disease-related issues, and their intricate connection with socioeconomic and environmental benefits.

- **Arcos Dorados – Recipe for the Future:** Arcos Dorados is pursuing a value chain approach that integrates all stakeholders involved in the production of specialized animal products, emphasizing quality and environmental sustainability throughout the entire process, from farm to table. This serves as a noteworthy example of how consumers can drive positive changes in animal production through a holistic perspective that encompasses best production practices, safety measures, animal health, transportation, storage, distribution, and education regarding sustainable consumption.

4. Questions and answers

These were some of the questions and answers that resulted from this live presentation.

Question: What is the role of public and private partnerships?

Mr. Barcos highlighted the significance of public-private partnerships in addressing animal health concerns, which include over 250 cases. Many of these cases are accessible on the WAOH website in Spanish, English, and French, emphasizing the framework's long-term sustainability. Notable examples were provided, such as Uruguay and Colombia, where funds were collected to invest in animal health and reproductive practices within the cattle sector. Colombia, specifically, used these funds to implement good practices aimed at reducing antibiotic resistance. Similarly, several South American countries have been actively involved in vaccine development.

Furthermore, Health for Animals in Africa offers veterinary services and has established reference laboratories for diagnosis. Vaccine banks have been established in various regions around the world. As part of African projects, agreements are reached to gather and share information regarding diagnoses, production, health, and factors impacting animal health. Additionally, public and private partnerships offer vaccination campaigns, with private actors also contributing other veterinary products.

Question: What is the status of access to veterinary services and digital tools for veterinary diagnoses and recommendations in the developing world?

Access to veterinary services in the developing world is supported by community volunteers. Digital tools are employed to report to authorities, but for the actual animal health aspect, confirmation is typically obtained from a qualified veterinarian. There is a significant opportunity to expedite diagnoses and recommendations using digital tools. Bolivia has faced similar challenges, with limited access to private services due to cost, highlighting the need to develop local capacities.

According to Health for Animals, there has been an overall improvement in global access to veterinary services. Emphasis is placed on the importance of public-private collaboration to enhance response capabilities for producers regarding diagnoses and recommendations. Nevertheless, the challenge of extending coverage in various regions persists.

Question: What is the regulatory framework for animal health?

Regulatory frameworks exist at both international and national levels. International regulations adhere to standardized principles for animal health. However, national systems can vary significantly from one country to another. Successful adoption and implementation of regulations require prior discussions involving all relevant stakeholders.

Regulations should involve key participants throughout the supply production chain. Market dynamics play a vital role in setting conditions and making benefits visible to participants. Additionally, the geographical coverage of regulations across multiple countries is a crucial issue deserving attention.

Question: Regarding the relationship between diseases and GHG emissions, what are the current research trends and limitations?

While one of the panelists mentioned the link between diseases and greenhouse gas (GHG) emissions, there is limited research in this area. Existing studies have focused on the social and economic aspects of diseases, with less attention to their environmental impact. One environmental concern is water contamination resulting from deceased animals. Budget constraints in many countries have hindered further research into this issue.

Question: Is Arcos Dorados sourcing meat from NAMA (Nationally Appropriate Mitigation Action) farms with low GHG emissions in Costa Rica, particularly those free from deforestation?

During the panel discussion, it was clarified that Arcos Dorados is collaborating with all stakeholders in the supply chain to promote "NAMA Ganaderia" in Costa Rica with MRV (monitoring, reporting, and verification). This means that, in the short term, some NAMA farms may become connected with this differentiated market, including those that have low GHG emissions and are free from deforestation.

5. Closing remarks

Emerging diseases in recent years have triggered significant societal responses. The case of the Covid-19 pandemic underscored the importance of public awareness and engagement. In 2021, ILRI-UNEP produced a document addressing zoonotic diseases, which prompted stakeholders to emphasize the significance of the One Health approach. Although this approach is not new, numerous institutions, including CATIE, have actively contributed to this theme, incorporating various strategies.

Several key drivers related to diseases have been identified, including:

- The growing human demand for animal-based food sources
- Unsustainable intensification of agriculture
- Increased exploitation of wildlife
- Unsustainable use of natural resources
- Changes in food supply
- Climate change exacerbating disease dynamics
- The impact of diseases on social and economic factors

Collective actions among stakeholders have been focused on various aspects of the value chain, including:

- Development of vaccines
- Advancement of new diagnostic technologies
- Exploration of alternatives to antibiotics
- Implementation of biosecurity measures
- Conducting more studies on the socioeconomic impact of diseases
- Facilitating data and information sharing, as well as educational materials
- Enhancing the use of digital tools
- Improving the delivery of veterinary services

Next steps in this endeavor include:

- Rejuvenating the professional workforce to effectively implement the One Health approach
- Prioritizing the health of animals
- Promoting sustainable animal production with a keen focus on animal welfare
- Ensuring access to veterinary services
- Emphasizing private sector participation.

ANNEX 3

WEBINAR 3

GEOPOLITICAL AND SOCIOECONOMIC DRIVERS

1. General information

Webinar Title: Geopolitical and Socioeconomic Drivers

Date: September 11, 2023

Moderator/Facilitator: Mariel Merayo, LLM / Danilo Pezo, Ph.D

Coordination: Felipe Peguero, Ph.D / Ileana Avalos, Ph.D

Panelists/Speakers:

Welcome Address

- Shirley Tarawali, Chair, GASL (Global Agenda for Sustainable Livestock)
- Muhammad Ibrahim, Director General, CATIE

Introduction

Henning Steinfeld, Consultant, GASL

Panelists

- David Anderson, Professor and Livestock Economist at Texas A&M University
- Alejandro Acosta, Livestock Economist, FAO
- Francisco Abello and Yuri Calil, professors and extension economists at Texas A&M University
- Carlos Pomareda, CEO of SIDESA, consultant, and ex-director of IICA Policy Program
- Jean-François Hocquette, Research Director, INRAE
- Felipe Peguero, Specialist in Ag-Economics and Climate Finance, CATIE

Number of participants: 93

2. Event summary

The webinar was focused on geopolitical and socioeconomic drivers shaping livestock systems. The speakers covered a range of drivers such as population growth, income expansion, urbanization, consumer perception, productivity factors, consumption patterns, trade policies, incentives such as climate finance, geopolitical tensions, armed conflicts, among others that affect supply and demand of livestock products.

3. Geopolitical and socioeconomic drivers

As follows we define the relevant drivers affecting demand and supply in livestock systems.

1. Population. It includes population growth, demographic composition, and migration.
2. Per capita income growth. It can be at the country level or at the individual level.
3. Economic growth of large economies. Refer to countries such as China with declining economic growth rates, which are big importers of livestock products.
4. Consumer preferences for livestock products. It includes taste, quality, nutrition, appearance, cultural values, organic/conventional, environmentally sustainable, etc.
5. Availability of livestock products. It refers to the amount, quality, variety, and type of product (organic, inorganic, sustainable with labels, among others).
6. Price. It implies the cost of livestock products at the consumer level or farm gate and how it changes given chocks in supply and demand.
7. Productivity improvements or total factor productivity refers to how much output is produced given a set amount of input.
8. Trade. It refers to trade policy, the volume of goods exchanged between countries, trade tension, among others.
9. Market incentives – profit. It refers to the level of profitability of farms given market conditions.
10. Rules, regulations, and certification regarding sustainability or environment.
11. Production risk, especially climate change risk. But also include market and technical risk.
12. Macroeconomic policies targeted to the livestock sector or broadly.
13. Market efficiencies. It refers to price transmission in the sector.
14. Government Investment: Government support through investment.
15. Carbon markets: Compliance and voluntary carbon markets availability and accessibility.
16. Government policy – export, for example, Argentina's policy resolutions to control inflation on livestock products.

17 Foreign Direct Investment from developed nations to the livestock sector of developing countries.

18 Russia-Ukraine War. The effect of the war on inflation, supply and demand.

19 Access to finance. It refers to traditional and climate finance at the farm level or value chain.

20 Consumer perception of meat production produced traditionally or sustainably.

4. How do drivers work?

1. **Population:** Population growth has always pushed up demand for livestock products in absolute terms. Likewise, changes in demographic composition in some regions. For instance, by 2050, the population of Africa, Oceania, South America, and Asia is expected to increase by 79, 30, 14, and 13%, respectively. Population growth is even greater in urban areas, far away from production areas, meaning higher demand infrastructure, value chain logistics, roads, and cold chains.

2. **Per capita income growth:** The rising income worldwide has been a trend for many years, increasing per capita demand for livestock products. As income grows, the livestock products demand increases because people upgrade their diets. Evidence suggests the higher the per capita income, the higher the meat consumption. However, most countries with per capita income lower than $10,000 eat less than the recommended 55 kg of meat per capita per year.

3. **Economic growth of large economies:** The largest economies are large importers of livestock products, as their economy decelerates demand is reduced.

4. **Consumer preferences:** Demand for livestock products changes as consumer preferences change, which in turn is affected by income growth, urbanization, cultural values, among others. A greater preference for sustainable livestock products may shift demand, but it might be constrained to wealthy countries since they are willing to pay more for products with "sustainability labels." Preferences for taste, nutritional attributes, quality, and sustainable products vary across people, countries, and regions.

5. **Availability:** On the demand side, more variety of products available induces more consumption. For instance, the availability of sustainable livestock products at competitive prices may increase demand over time.

6. **Price:** Prices of livestock products are a significant driver of demand. However, prices are the result of supply and demand factors. Over time, prices of livestock products have decreased in relative terms, pushing up the demand. Shocks in supply and demand can affect prices significantly, consequently affecting food security or farm profitability. Although the livestock price elasticities of demand are mostly inelastic, the shock effect on prices varies across regions and products. The less inelastic livestock products are poultry, followed by pork, beef, and lamb.

7. **Productivity improvements:** Through time, farmers have achieved significant yield gains, although uneven across regions. This means reduced resource use per pound of meat/milk produced. These gains in productivity

have come from adopting technologies and practices (technological change drivers) such as better nutrition, genetics, management, etc. Consequently, these gains in productivity could increase profit and motivate the expansion of livestock production systems.

8. **Trade:** Trade exchanges among countries have increased over time, which has led to economic growth, rising income, and lower meat prices in importing countries, thus boosting demand in importing countries and supply in exporting countries. However, small countries with inefficient livestock systems are facing pressure from current free trade agreements. The push for continued reduction in trade barriers has waned in some markets, translating into fewer free trade agreements, export bans, and retaliatory tariffs. Current trade tensions are threatening livestock and meat production growth, exacerbated by recent wars and civil wars.

9. **Market incentives – profit:** The profit opportunities in the livestock sector are driving the increase in the production of livestock products, which translates into more offspring and GHG emissions. In that search for profit, farmers expand production or improve their production systems to meet local or export opportunities.

10. **Rules, regulations, and certification regarding sustainability or environment:** As the sustainability agenda has moved forward, countries and food value chains are encouraged to establish regulations or certification schemes. These policy drivers may shift traditional production systems toward sustainability but also create differential costs, which could discourage farmers if they do not cope with incentives to keep or improve profitability.

11. **Production risk:** Climate change has increased the production risk, leading to higher costs to mitigate climate risk, and in some cases, the production risk has become so big that some regions are no longer profitable.

12. **Macroeconomic policies:** Macroeconomic policies affect livestock systems by affecting demand and supply.

13. **Market efficiencies:** Price transmission of shocks such as import are relevant for farmers and merchants of livestock products since they affect price expectation and, therefore, decision making. Consequently, supply is affected.

14. **Government investment:** Government support through investment in livestock systems impacts production efficiencies. These impacts are short or long-term, depending on the quality of the investment and the duration.

15. **Carbon markets:** Compliance and voluntary carbon markets are a way to incentivize farmers to reduce emissions and sink carbon. Mandatory and voluntary markets have different prices per ton, changing across regions and industries. Prices need to increase to encourage emission reduction over time.

16. **Government policy – export taxes:** Some countries like Argentina impose policy resolutions to control inflation on livestock products (i.e., meat) by imposing tariffs on exports. Such policies aim at protecting consumers but significantly impact export, production, and evolution of production systems.

17. **Foreign direct investment:** The livestock sector in some developing countries (i.e., Brazil) has evolved due to foreign direct investments deployed in livestock farms, factories, and the value chain. These financial flows have been motivated by the export market. Such investments have also been allocated to the grain sector supplying animal feed.

18. **Russia-Ukraine war:** The effect of the war has translated into inflation in the livestock systems. Fertilizer prices increased significantly as a consequence of the war, affecting the production cost of grain to feed the animals.

19. **Access to finance:** The expansion of livestock and technological changes usually come from self-funding, private or public loans, or government programs. Traditional finance funding livestock systems will continue fostering the business-as-usual scenario contributing to climate change, unless climate finance mechanisms could support the sector's transformation if made available to end users.

20. **Consumer perception of meat production:** Consumers' long-standing, well-perceived perception of livestock has shifted in the last two decades due to environmental concerns, increasing the triggers to substitute animal protein with cultured meat and vegetable protein. These perceptions change across regions, economic status, and people's age.

5. Potential solutions

Some recommendations for reducing the negative impact of geopolitical and socioeconomic drivers that emerged from the webinar are as follows:

1. Recognizing the differences between countries regarding drivers' impacts and potential interventions for tackling the constraints. This implies countries and livestock systems taking advantage of the opportunities sprung from location, income growth, population growth, population structure, trade, and others. For example, how the increased demand for beef or milk has affected the expansion of pastureland at the expense of forest and how the Brazilian Forest Code and price incentives for free deforested beef in some way helped to reduce deforestation in the Amazon region.

2. Updating and communicating data on the price elasticity of demand for livestock products for different countries considering the potential effects of shocks in supply and demand in response to different drivers.
3. Understanding the most important criteria during livestock food purchase, i.e., sensory quality, price, safety, origin/traceability, ethics, nutrition, environment, appearance, label, energy intake, and production. Since these change across countries and populations, targeted intervention should be differentiated.

4. Understanding the gaps in productivity growth across countries and the factors affecting productivity could lead to better intervention programs across regions.
5. Training and supporting farmers to access mandatory and voluntary carbon markets to incentivize them to reduce emissions and

enhance carbon sequestration in livestock farms; however, carbon prices need to increase to compensate for abatement costs. Small farmers could access such mechanisms as a group to reduce the transaction cost.

6. Projects to transform the livestock sector should consider the success of some foreign direct investment initiatives to supply the export market with deforestation-free livestock products and their tracking and monitoring mechanism employed (i.e., Brazil).

7. Efforts to forecast and share information on potential impacts of climate change, changes in market prices and conditions at local and global levels, as well as political decisions, are essential for all stakeholders to make proper decisions.

8. Projects to transform livestock systems should work with financial institutions to help them understand their carbon footprint. Furthermore, operationalizing climate finance should focus on establishing financial mechanisms and building capacity so the banks may internalize mitigation and adaptation metrics. Thus, traditional financing portfolios can be transformed toward more sustainable pathways.

9. Cultivated meat products may become a significant substitution source of animal protein. As production cost is reduced and sensory parameters improve over time, it may become a major driver in the decline of animal protein demand. Thus, more research is required to understand its socioeconomic potential impact, especially in developing nations, and how to cope with it.

10. Projects should carry out case studies in those countries that have pledged for C-neutral livestock systems to generate data on the feasibility of those strategies at the national level, which eventually could serve as models for other countries.

11. Support farmers with more capacity building to implement sustainable practices and at the same time try to incentivize younger generations into the livestock systems. Also, we need to clean the negative image of the livestock sector because it also discourages farmers and new generations to continue in the sector.

6. The role of the multi-stakeholder approach

The solutions in response to the drivers negatively or positively affecting livestock systems should be tailored to the reality of each country and sector. Thus, this global discussion should continue at the country level where FAO has offices. Then, in coordination with local authorities from the government, private sector, academia, the banking system, and NGOs, the industry should enrich the global findings and customize solutions for the local reality.

7. Questions and answers

The following is derived from questions asked of panelists after their presentations.

What is your view about the small livestock producers in the developing world?

- Over time, the number of farmers has decreased in developed countries (e.g., in the USA and Europe) and in middle-income countries in Asia (e.g., China, Thailand, Vietnam, Indonesia) and Latin America (i.e., Brazil, Mexico). However, this is not the case for low-income countries where landless and small farmers are the majority. Also, in these countries the age of farmers has increased, and few young people are interested in farming. That situation makes us have a pessimistic view of the future in developing countries.
- Farming is becoming even bigger in the U.S., and more younger people are joining the industry.
- Small farmers also have growth opportunities, but it is challenging because of economies of scale. There is a need to put policies in place so they can stay in business and thrive. It could be genetic improvement, cooperatives that help with marketing, and promoting those, not scale-neutral technologies. The big problem is that many current technologies are not scale-neutral, and how do we identify the appropriate one for small farmers?

How do you build domestic consumer demand?

- Let's think about pork, beef, and chicken. There is a lot of dynamic between these three and between cuts. However, the per capita consumption has not grown in the USA in the last decade; most of the growth has gone to export. For instance, genetic improvements have created leaner pork that dries too much and has poor flavor. Therefore, there is a need to create a program to boost domestic demand by improving genetics and selecting for flavor and moisture.

How has the Russia-Ukraine war affected the livestock sector in America?

- Ukraine is a big supplier of wheat and corn. Wheat is a grain for human consumption, and corn for animal feed. Overall, the war has created corn scarcity, raising the cost for livestock production, and in a world market, this affects everybody. At the same time, the price signal makes U.S. farmers respond by planting and exporting more corn. Consequently, corn prices are declining again, which reduces the livestock cost. Therefore, the effect of the U.S. livestock systems is more indirect through price signal and feed cost.
- The last two decades have transitioned from traditional to more sustainable livestock systems. What is the most

relevant driver of such changes, and what can we do to increase the transition?

- Profit is the main driver. For instance, if we decrease the age of first calving and the age of slaughter, then profit increases and emissions decrease.
- Profitability for the long run. Farmers have become more conscious of keeping the farm profitable in the long run for the next generation. Thus, they take action to protect the soil and the land use.
- Political frameworks in Brazil. For instance, each farmer needs to provide a GPS reference to the government; that way, it can check if the farmer is deforesting. Also, the law says you should have at least 30% of the land intact.
- Access to premium markets: To access premium markets, farmers need to be sustainable. In that case, being sustainable can bring profitability.
- Decreasing margin in the livestock sector forces livestock farmers to become more efficient to stay in business. Consequently, some efficiency is linked to lower emissions per unit of product.
- Does cultivated meat generate emissions?
- Some studies suggest that cultivated meat generates much less emissions than conventional meat, while others don't find conclusive evidence after accounting for direct and indirect emissions. It needs more research.

How do you maintain the cultivation of lab meat clean?

- Companies argue that lab meat is clean; some recognize they use antibiotics. About 50 questions regarding food safety have not been answered yet, according to FAO. So, it is unclear if cultivated meat is clean.

Can small farmers easily access carbon credits?

- No, because of the carbon sink measurement difficulty for small farmers and the transaction cost.
- Also, remuneration for carbon sunk or reduced is very small.
- So, economy of scale matters here because these are long-time contracts that sometimes involve lawyers. For example, if you have 50,000-100,000 hectares, the income may be small, but it may be enough to cover the transaction cost.

Enforcement in Brazil for things such as deforestation

- It isn't easy because Brazil is so big.
- There is also a problem with traceability.
- But at least there is a monitoring system to check if farmers are deforesting.
- Also, there is a lot of effort to protect the forest and produce sustainably.

8. Conclusion and final reflections

Socioeconomic and geopolitical factors play a crucial role in shaping the supply and demand dynamics of livestock products. Population growth, for instance, escalates demand, whereas demographic shifts alter consumer preferences. Urban migration necessitates adjustments in logistics and infrastructure to satisfy this evolving demand. Rising per capita income typically leads to dietary upgrades, thereby boosting demand. Conversely, economic slowdowns in major economies like China can diminish their imports of livestock products. Consumer tastes, which are dynamic, significantly influence demand and the price consumers are willing to pay. Livestock companies must stay responsive to these evolving tastes, especially as a wider array of products, including sustainable options, may stimulate consumption.

Price dynamics, primarily governed by supply and demand, tend to be relatively inelastic for livestock products. Technological advancements are key in enhancing productivity, a primary factor in supply growth, often driven by the lure of higher profits. Trade policies have been instrumental in economic development, but the enthusiasm for reducing trade barriers has diminished in some regions, leading to fewer free trade agreements, export bans, and retaliatory tariffs.

Sustainability-focused rules, regulations, and certifications are nudging production systems towards eco-friendliness but may introduce additional costs that could deter adoption by farmers. Climate change has intensified production risks, increasing the expenses associated with climate risk mitigation. Finally, macroeconomic policies and market efficiencies, through their impact on price transmission, shape farmers' expectations and, in turn, influence supply.

Government short-term investment generates short efficacies that eventually decay; thus, countries should focus on the quality of the investment for the long term. Carbon markets are a way to incentivize mitigation in livestock farms, but carbon prices need to increase. Some government policies, such as export taxes, not only affect export but production systems as well.

Foreign direct investment has not only boosted exports in several South American countries but also encouraged farmers to commit to sustainable practices. The Russia-Ukraine war translated into inflation in livestock production systems due to early scarcity of corn and fertilizer, but prices are stabilizing. Finance will continue fostering the business-as-usual scenario, contributing to climate change unless climate finance instruments become mainstream for livestock systems. Consumer perception of meat production has become negative due to environmental concerns, increasing the triggers to substitute animal protein with cultivated meat and vegetable protein. These perceptions change across regions, economic status, and people's age.

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