Food Security and Livestock: A Comprehensive Review of Sustainability, Challenges and Innovative Solutions

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Abstract

Livestock systems are of significant concern to global food security, providing basic nutrition and livelihood alongside serious environmental problems. The dual functions of livestock are revealed in this review, i.e, they are essential for billions of animal-derived foods for livelihood and nutrition, but they promote climate change and resource degradation. Smallholder systems within the middle- and low-income countries operate to assist the communities, women included, through poverty reduction and stunting elimination but are liable to environmental stress. Industrial systems within high-income countries seek efficiency at the cost of augmenting inequalities and degradation. Animal-derived foods are nutrient-rich and essential for proper growth and development. However, with the rapid increase in population, the rising demand for meat and dairy products raises sustainability concerns, particularly given the significant contribution of the livestock to greenhouse gas emission and resource consumption. But their implementation requires

strategic planning and sustained investment. To reconcile livestock uses with environmental needs, an integrated approach is needed, comprising climate-smart subsidies and carbon pricing. Future research has to be focused on livestock systems that are resilient to climate, impartial access to technology, and incorporation of health and disease resistance aspects for reducing the risk of Zoonosis. Livestock will eventually play a central role in food security, and their sustainable future depends upon the unification of traditional knowledge and science and making food policies more reasonable.

Key Words: Livestock. Food security, sustainability, Climate change, Animal source food (ASF)

1. Introduction

As per Food and Agriculture Organization (FAO) 2021, livestock systems contribute directly to employment and income, taking the global number of supporting people to 1.3 billion people around the globe. Livestock systems also account for 40% of agricultural GDP (Gross Domestic Product) and 34% of the world protein supply. Food security is defined by FAO the as a condition where every Human being, at any given time, has reach to physical, social, and economic resources that can provide adequate, safe, and healthy food. Food security is perhaps one of the portentous issues that remains unsolved (Leroy et al., 2022). With population increase, climate shifts, and geopolitical disruptions, livestock systems have become an integral component in the multitude of food security frameworks throughout the globe (Beal et al., 2023). Livestock covers all four pillars of food security: availability, access, utilization, and stability (Leroy et al., 2022). Their importance is not limited to only food production but also includes economic, social, and environmental aspects which makes them an essential component of both global and national food systems (Abu Hatab et al., 2022).

ASFs (animal source foods) like meat, milk, and eggs are also incredibly nutritious foods that include the essential building blocks of life like Vitamins, Micro and Macro Minerals (Beal et al., 2023). These Animal-derived foods account for 18% of global caloric intake and meet 34% of the protein needs. According to World Health Organization (WHO) in 2022, Animal-derived foods, especially milk, provide the necessary calcium and cover 14% of dietary needs. Studies suggest that deficiency of livestock-derived protein is linked to stunting and high anemia rates among children and women, especially during pregnancy in low-income countries (Smith et al., 2015).

Livestock provide resilience, too, beyond nutrition(Abu Hatab et al., 2022). They serve as living investments for smallholder farmers, providing a barrier against crop failures and economic losses (Shahbaz et al., 2022). Livestock are key to getting into diverse diets and health benefits in sub-Saharan Africa and South Asia, provided that 20–50% of total household income (Kolawole et al., 2022). In addition, livestock by-products manure as fertilizers, hides for the textile industry, and draught power for ploughing, boost their value chain footprint. For example, manure is used for soil fertility on 60% of the world's agricultural land, reducing their dependence on synthetic fertilizers (Choi et al., 2017; USDA, 2021).

But livestock's role is a double-edged sword. So, they strengthen food security, but such unsustainable practices undermine environmental stability (Singh et al., 2023). Livestock contribute 14.5% of greenhouse gas emissions due to anthropogenic practices in livestock rearing and production, and are responsible for rainforest deforestation, while livestock farming uses 30% of the freshwater resources globally (Hoekstra et al., 2012). Ethical worries about intensive farming and the risks of diseases jumping from animals to humans make their story even more complex. Finding a balance between high output and long-term sustainability is key to sorting out how livestock can help and support food security (Abu Hatab et al., 2021). Emerging issues related to livestock production highlight the need for incorporation. Alternative proteins, like plant-based and lab-grown meats, challenge traditional livestock-derived meat and protein sources, but their scalability and acceptance in LMICs (Low and Middle-Income Countries) are unclear (Abu Hatab et al., 2022). Climate adaptation, particularly livestock's role in climate-resilient farming, is less studied than mitigation strategies. The COVID-19 pandemic emphasized zoonotic risks, calling for integrated livestock management practices (Abu Hatab et al.,2021).

This article reviews studies on how livestock helps with food security and sustainability. It will examine the effects of livestock on nutrition, economics, and the environment in several farming regions of the world. Finally, it will propose methods to ensure livestock farming is fair and sustainable for food security. This review focuses on monogastric (poultry, pigs) and ruminants (cattle, goats, sheep) across small household and industrial setups. It talks about poor and middle-income countries where farm animals help fight poverty and covers worldwide trends. By integrating a multidisciplinary approach, this review provides a roadmap for leveraging livestock systems to achieve sustainable development goals, i.e., zero hunger without impairing terrestrial boundaries.

2. Livestock's contribution to food security

Livestock products are unmatchable in their efficiency in providing essential nutrients that are readily metabolized by the human body (González et al., 2020). In high-income countries, animal source food constitutes about 60-80% of the diet while in LMICs it accounts for 20-30%, serving as a crucial component of plant-based diets (Lokossou et al., 2021) . Additionally, animal-derived foods are the only dietary source that contains all nine amino acids necessary for growth and immune function (González et al., 2020). For example, the egg's protein digestibility corrected amino acid score is 1, the highest among all other food products (Iannotti et al., 2014). Vitamin B12 is one of the essential Micronutrient that are available from animal-derived foods; scarcity impacts 15–40% of the global population, including vegans and the elderly (Smith et al., 2013). Iron and Zinc, the essential Micronutrients their importance for human health is not a debatable topic; meat containing heme iron which is 2–3 times more bioavailable than iron from plants, lowers the anemia levels in children (Silva et al., 2025). One of the most important micronutrients is calcium. Calcium requirements are met by 70% of the population by consuming dairy (Global

nutrition report, 2021) (Livestock and Poultry: 2025). Table 1 represents the key products of animal source of each country along with their GDP share of livestock in the year 2023-24.

Table 1. Livestock GDP share of different countries to their national economy and their livestock products, which shows the liking of each nation for animal-source food

Country	**Year**	**Livestock GDP share**	**Key Livestock Products**	**References**
United States	2023-24	0.8%	Beef, Pork, Dairy, and Poultry	(World Food and Agriculture - Statistical Yearbook , 2023)
Brazil	2023-24	6.24%	Beef, Poultry and Pork	(Livestock and Poultry: Market Shares of Global Trade, 2025)
China	2023-24	6.8%	Pork, Poultry, and Eggs	(National Bureau of Statistics of China, 2024)
India	2023-24	6.1%	Milk, Beef and Poultry	(Ministry of Agriculture and Farmers Welfare, India, 2024)
Australia	2023-24	2.4%	Beef, Sheep, and Wool	(Anderson, 2024)
Germany	2023-24	0.8%	Pork, Dairy, and Poultry	(Performance of the Agricultural Sector Statistics , 2024)
New Zealand	2023-24	6.4%	Dairy, Sheep, and Beef	(Westpac Banking Corporation., 2024)
Pakistan	2023-24	14.2%	Beef,sheep, Dairy and Poultry	(Pakistan Bureau of Statistics, 2024)
Argentina	2023-24	9.83%	Beef and Dairy	(Argentine Economic outlook, 2024)
South Africa	2023-24	2.9%	Beef, Poultry, and Sheep	(Soth Africa Bureau of statistics, 2024)
Kenya	2023-24	5.2%	Dairy, Beef, and Goat Meat	(Kenya National Bureau of Statistics, 2024)
Canada	2023-24	7%	Dairy, Pork, and Poultry	(Statistics Canada, 2024)
France	2023-24	1.3%	Beef, Pork, and Dairy	(Eurostat, 2025)
Russia	2023-24	3.35%	Dairy, Beef, and Pork	(Rosstat, 2024)

Mexico	2023-24	19.6%	Pork, Poultry, and Beef	(National Institute of Statistics and Geography, Mexico, 2024)
Nigeria	2023-24	10%	Poultry, Beef, and Goat Meat	(National Bureau of Statistics Nigeria, 2024)
United Kingdom	2023-24	0.5%	Beef, Dairy, and Sheep meat	(DEFRA, 2024)
Ethiopia	2023-24	19%	Cattle, Sheep, and Goat meat	(Central Statistical Agency of Ethiopia, 2024)
Bangladesh	2023-24	1.85%	Poultry, Beef, and Milk	(Bangladesh Bureau of Statistics, 2024)

Livestock systems have an important role in economic development, especially in agricultural economies, as they generate more than half of agricultural GDP and employment and support rural livelihoods. Livestock production accounts for around 40% of the total agricultural GDP in the world, and the figure increases to 60% in pastoralist communities like East Africa (Lane et al., 2025). In a report by FAO published in 2021 apart from its macroeconomic role, livestock production supports the livelihood of approximately 1.3 billion individuals across the globe, including smallholder farmers, processors, and traders. Livestock keeping is also a principal poverty-reduction strategy through divergence of income. Studies shows that livestock-owning households have 35% lower chances of slithering into poverty, further emphasizing the importance of this sector in strengthening economic resilience (Elzaki et al., 2019). Thus, livestock systems not only promote economic growth but also facilitate financial and social stability within rural society (Conrad et al., 2018).

3. Challenges Faced by Livestock Production and Food Security

Climate change itself is aberrant in livestock sustainability through the rise in temperature and variability in rainfall patterns, affecting both livestock production and resource value unswervingly. Heat stress, for example, has been reported to decline dairy production among dairy animals by 10–25 % and poultry egg production by about 20 percent, which advocates that livestock systems are susceptible to ecological temperatures means (Kauffman et al., 2022). Moreover, prolonged droughts mutilate feed shortages, with disastrous effects on pastoralist communities. For instance, in 2020 and 2023, the Horn of Africa was hit with ferocious droughts that slain about a crore of animals, enervating millions of resources of living as cattle farmers (FAO, 2023). Additionally, livestock production is the most significant source of greenhouse gas emanations, with ruminants like cattle contributing to almost 80% of the sector's total productions, mainly through intestinal fermentation (Kyttä et al., 2025). Kyttä et al., show that all these issues

acme the importance of climate-resilient animal management practices to provide long-term sustainability and food security.

Livestock-derived zoonotic diseases are a momentous threat to global health, food security, and economic stability and require vigorous biosecurity measures. Avian influenza, the H5N1 epidemic 2021–2023, resulted in the getting rid of about 140 million poultry birds, generating a 60 percent increase in egg prices in the United States, which is an attestation to the far-reaching economic consequence of disease epidemics (World Bank Annual-Report, 2023,). Equally, African Swine Fever ruined the world pork corporation, killing 50 percent of China's pigs in 2019 and causing devastation across global meat supply chains (Cheng et al., 2022). Besides unexpected epidemics, the disproportionate use of antibiotics in rigorous animal production gave rise to antimicrobial resistance (AMR), a forthcoming emergency that will kill 10 million people every year by 2050 if not tackled (Liang et al., 2023). They highlight the inevitability of stringent biosecurity, appropriate disease management practices, and international collaboration in plummeting the potential hazards from zoonotic disease agents and firming up global food chains. As illustrated in Fig. 2, the complex relationship between conflicts effecting food security and potential solutions highlighting the need for integrated approach.

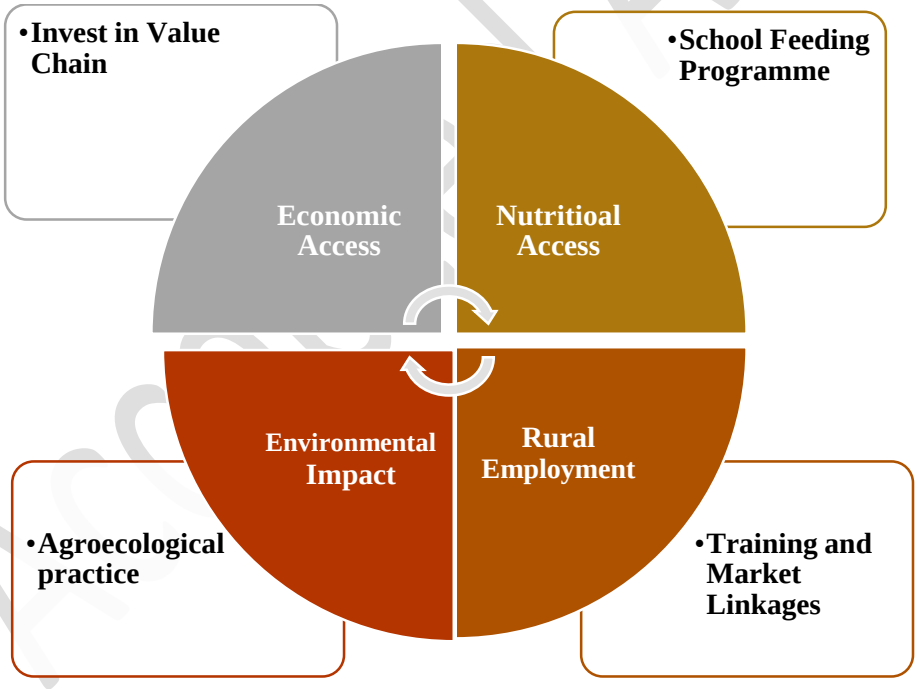

Fig. 1: A Linkage showing Conflicts about Food security and their solution.

4. Strategies for Sustainable Livestock Production and Food Security

Technological innovations in animal husbandry practice, i.e., precision livestock farming and genetic modification, are revolutionizing efficiency, enhancing disease resistance, and improving

environmental stability. Precision Livestock Farming (PLF) uses devices and artificial intelligence to track animal health and make the best use of these resources. For example, udder-wearable sensors for dairy cattle have been used to reduce mastitis occurrence by 30%, bring about animal well-being, and yield (Liu et al., 2019). Moreover, technological advances in the feed-making process, e.g., the incorporation of methane inhibitors such as 3-nitro-oxy propanol (3-NOP), have registered a 30 percent reduction in methane emissions by livestock without loss of milk production, encouraging livestock system sustainability (Homem et al., 2024). These advancements imitate the prowess of innovation in adapting livestock efficiency, resistance to disease, and environmental stability.

Policy measures have a significant role in influencing the sustainability, economic performance, and environmental interconnectedness of animal production through some principles and trade policies. Administrative subsidies supporting livestock management that are climate resilient, like some countries, have introduced the Climate-smart livestock program, which encouraged the uptake of drought-resistant forage crops, with commercial and food security advantages for about 500,000 pastoralists (Lopez-Ridaura et al., 2018). Furthermore, mechanisms of carbon assessment, like the one proposed by European Union imposing tax on methane, provide monetary incentives for emissions extenuation in beef and dairy animal farming and more justifiable modes of production. Trade policy also has a considerable influence on the production price of livestock as well as market trustworthiness (Lovarelli et al., 2023). As we have witnessed, eliminating import duties on chicken feed in Egypt reduced chicken production costs by 15%, illustrating the success of openness in promoting competitiveness and industry productivity (Iannotti et al., 2014). Overall, these policy reforms illustrate the merit of regulatory intervention in enabling the development of a more sustainable, economically strong, and efficient livestock industry.

Table2. Research-Based Findings and policy implementation of livestock's Multidimensional role.

Feature	**Status**	**Policy Implementation**	**Reference**
Economic Aspect	Livestock subsidizes 40% of agrarian GDP in Sub-Saharan Africa, thus supporting smallholder incomes.	Capitalize in livestock value chains (e.g., feed and feeding systems, cold storage) to stabilize revenues and reduce poverty.	(The State of Food Security and Nutrition in the World , 2022)
Nutritional Aspect	Daily intake of ASFs reduces child stunting by 24 percent in pastoralist communities.	Integrate ASFs (e.g., milk, eggs) into institute feeding programs and maternal health ingenuities.	(Grace et al., 2018)

Feature	Status	Policy Implementation	Reference
Environmental Aspect	Ruminant livestock accounts for 14.5 percent of global GHG emissions, but mixed crop-livestock systems can sequester carbon.	Endorse agroecological does (e.g., silvo-pasture, compost recycling) to balance efficiency and sustainability.	(Masson-Delmotte et al., 2019)
Even-headedness	Women own 60–80% of livestock in LMICs but possess <10% of land titles, limiting access to credit.	Support women's land rights and provide gender-responsive monetarist tools (e.g., assemblage loans).	(Njuki et al., 2022)
Climatic Resilience	Drought-resistant livestock breeds (e.g., Boran cattle) upsurge household resilience by 30% during climate shocks.	Scale up breeding agendas and insurance structures for climate-adapted livestock species.	(Thornton et al., 2009)
Rural Employment	Livestock creates 130 crores of jobs worldwide, 70% of which are in informal areas.	Solemnize informal livestock areas through training, safety grids, and market links.	(Trends ILO Flagship Report World Employment and Social Outlook, n.d.)
Cross-Sectoral Policy	Only Fifteen percent of national food security policies openly address livestock.	Develop cohesive policies linking livestock, agriculture, and nutrition for general food security.	(World Bank Annual-Report, 2023)

Livestock systems are an imperative component of global food security, economic progress, and human nutrition but are confronted with the most serious challenges such as climate change, scarcity of resources, and environmental hazards (Kyttä et al., 2025). Increased temperature, water and feed shortages, and dangerous levels of greenhouse gas emissions require adaptative actions such as drought-tolerant breeds, precision livestock farming, and improved pasture management. Though animal-source foods provide essential nutrients, their environmental impacts underscore the importance of adopting balanced diet strategies that incorporate sustainable livestock development (Homem et al., 2024). Fig. 2 highlight the areas which should be prioritized by stakeholders for sustainable livestock production.

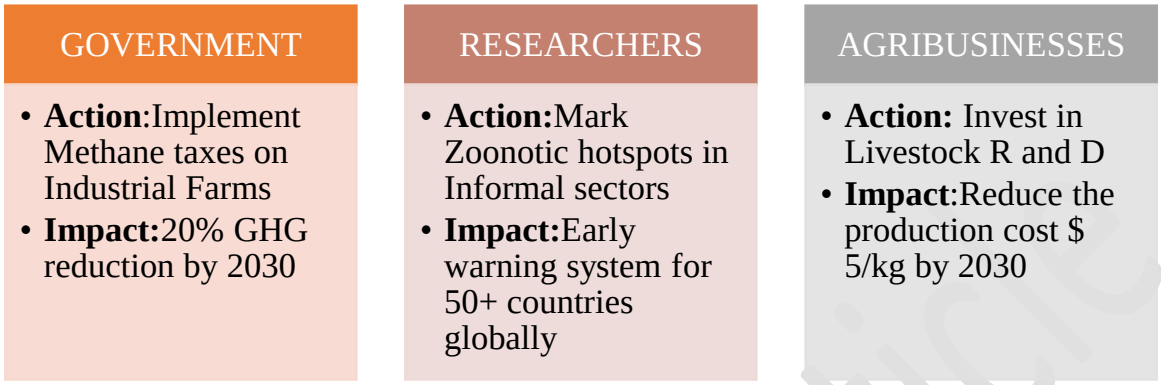

Fig. 2: Actions to be prioritized by stakeholders for Food Security.

Additionally, ensuring access to innovations such as Precision livestock farming and agricultural insurance to smallholder farmers is vital in constructing equitable and adaptable livestock systems (Pollard & Booth, 2019). This review synthesizes existing understanding of the interlink among livestock production, environmental sustainability, and socio-economic equity with a focus on the optimization of productivity without adverse effects. Through the integration of scientific progress with policy reaction, the review reveals the need for integrated methods to facilitate sustainable livestock development in the face of global challenges.

4.1 Livestock innovation for sustainable food security

There are extreme regional and systemic variations regarding the role of livestock in nutrition, economic development, and environmental sustainability, with (Pollard & Booth, 2019). Nutritionally, animal-source foods are largely considered the key to preventing micronutrient malnutrition in every setting, but especially in low-resource settings. Randomized controlled trials in Kenya and Bangladesh demonstrate that daily egg intake prevents stunting in children by 15–20% (Iannotti et al., 2014)(Headey et al., 2018). However, controversies persist on optimal ASF intake, with high-income countries concerned with ASF overconsumption leading to non-communicable diseases and LMICs by under-consumption (Mapes et al., 2022). From an economic point of view, livestock farming is a central living and resilience source, particularly for smallholder systems. However, industrial livestock production systems in high-income countries with high production are tilted towards small-producer marginalization, raising concerns regarding equity (HLPE-FSN Report, 2022). Environmentally, there is widespread consensus on the high carbon intensity of ruminant livestock, with beef having 6–10 times higher per kilogram greenhouse gas emissions than poultry (Conrad et al., 2018). However, regional differences persist:

extensive grazing in Sub-Saharan Africa is of lower emissions intensity but of larger land use, while intensive U.S. feedlots have the highest land use intensity but at the expense of water pollution (Eska et al., 2024). So, these studies reflect the multi-faceted nature of the role of livestock in sustainable food chains that need region-specific interventions to rectify nutrition, economic equity, and environmental sustainability. The timeline of policy and research milestones highlights crucial advancements in livestock sustainability supporting food security initiatives.

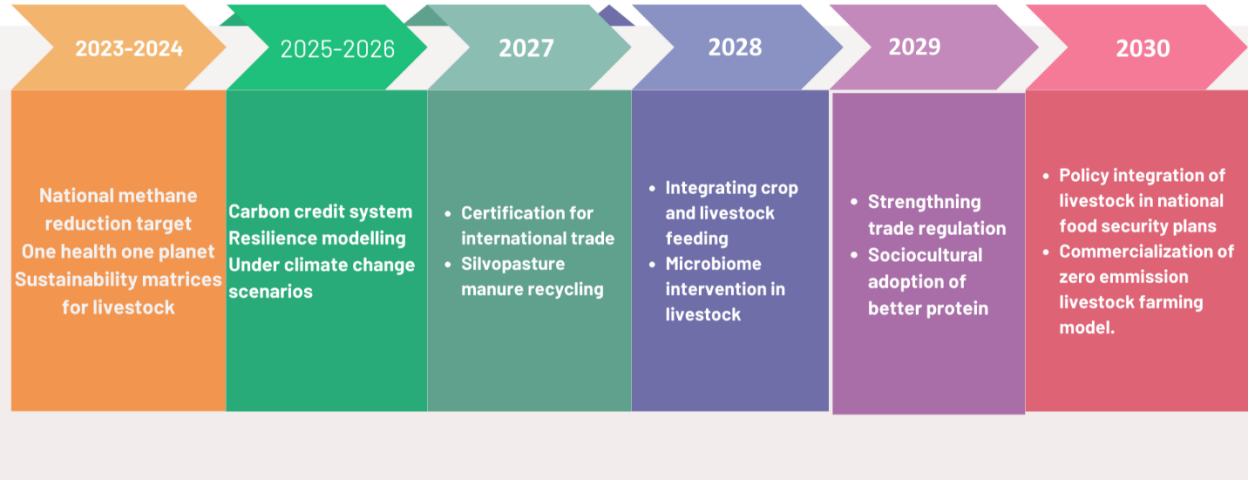

Figure 3. Timeline (2023-2030) for Policy and Research Milestones in Sustainable Livestock

The available literature on livestock systems and food security reveals numerous contradictions and suggests important knowledge gaps, most importantly on climate adaptation measures, alternative protein intake, and alertness to face zoonotic disease outbreaks (Lake et al., 2012). Agroecological sustainable silvopasture is one area of research that focuses on enhancing climatic durability, while others promote technical solutions, including the use of methane inhibitors; again, there is minimal evidence for tackling scalability and feasibility in developing countries (Eska et al., 2024). Analogously, alternative proteins like cultured meat are highly controversial in high-income countries, also, no empirical evidence on cultural acceptability and market accessibility is available for these in LMICs, where insect protein faces fewer sociocultural barriers (Kim et al., 2022). Again, zoonotic disease risk research is unevenly concentrated in other regions (Kim et al., 2022). Preparedness for Avian Influenza epidemics is comparatively good in Asia, while Africa's open markets for livestock indicate a high level of deficits in surveillance and response capabilities (DFID, 2012) . Filling these gaps is imperative to design equitable and region-specific measures for sustainable livestock production and food security at the global level (Lake et al., 2012) (Kyttä et al., 2025).

To enhance the value of livestock systems, a comprehensive research strategy and innovative approaches are essential for improving production. Developing long-term sustainability indicators such as net nutritional benefit per environmental cost is crucial for evaluating diverse livestock systems (Windsor, 2021). Resilience modeling is crucial for understanding how climate change will affect the livestock in the event of a 2°C or 4°C rise in temperature, enabling the selection of optimal adaptation strategies (Lovarelli et al., 2023).

Despite the wide-ranging literature on livestock and food security, critical knowledge gaps persist. Existing studies often fragment discussions into isolated themes like nutritional needs, economic impacts, or environmental impact, rather than adopting the integrated systems of livestock production. Few studies resolve the tension between livestock's indispensable benefits and their sustainability challenges, particularly in the context of climatic change and fluctuating dietary trends. ASF's are vital for nutrient-deficient populations, high-income countries face criticism for overconsumption and its ecological interconnectedness. This review bridges these contradictions by offering a balanced analysis that enlightens policy and innovation needed.

5. Conclusion

Livestock systems play a vital role in global food security by providing essential nutrition, economic benefits, and cultural values, yet they pose certain environmental and ethical challenges. For billions of people, ASF's are a critical source of nutrients and livelihoods. In LMIC's, smallholder livestock help alleviate poverty and malnutrition but also exert pressure on fragile ecosystem. Meanwhile, industrial systems in high-income countries prioritize efficiency but contribute to environmental degradation and social inequalities.
ASFs are important sources of protein, iron and vitamin B12. They can address malnutrition and provide income for women in low-middle-income countries. But rising demand for meat and dairy and climate pressures threaten system stability. Livestock generates 14.5 percent of greenhouse gas emissions and needs a tremendous amount of land and water, which calls for solutions now. Precision farming, new varieties genetically modified to resist drought, and other strategic innovations could help, but they need supportive policies and handsome investments.
A collaborative approach is essential to balancing benefits of livestock with environmental constrains. Policymakers should prioritize climate-smart subsidies and carbon pricing, researchers must develop sustainable metrics, and consumers in high-income countries should shift towards consuming less but better meat. Future research should focus on climate-resilient livestock systems, equitable access to technology, and integrated health strategies. As Livestock remains vital for food security, and success depends on merging traditional knowledge with modern science while ensuring equity in food policies for future generations.

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