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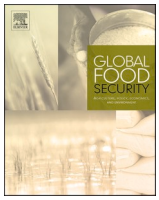

Context is key to understand and improve livestock production systems

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ABSTRACT

Ruminant livestock production is arguably the most varied, complex, impactful, and controversial land use sector of our global food system today. Despite calls for improved sustainability across the sector, progress has been limited. To advance effective solutions, there is a need to understand livestock systems and outcomes at regional scales, grounded enough in local conditions to be relevant, yet broad enough to be generalizable for policy or funding interventions. Using a comparative qualitative analysis of ten expert-led case studies from diverse agroecological regions and production systems around the world, we offer an updated approach to categorizing livestock systems, discuss relevant outcomes, and offer insight into the key contextual factors that influence current systems and potential for change. We find that in addition to livestock production system classes, economic (local, regional, and global economics and markets), environmental (biome suitability for ruminant grazing, land condition, precipitation), and social and cultural factors (land tenure, cultural embeddedness of livestock) are important to consider. Our case study analysis also shows that livestock management is typically motivated by at least five outcomes, with priority outcomes shifting from region to region, highlighting that livestock plays different roles, with different implications, in different places. We conclude that use of a context-based lens considering multiple outcomes and perspectives will likely improve the pace of progress toward environmental and social sustainability of livestock production.

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1. Introduction

Ruminant livestock production is arguably one of the most varied, complex, impactful, and controversial land uses and sectors of our global food system today (Herrero et al., 2015, 2023). In the public discourse, the value and role of livestock production is highly polarized (Béné and Lundy, 2023). Narratives often come from one point of view (e.g., climate or livelihoods or conservation) leading to radically divergent views of ideal futures (e.g., Wang et al., 2023). This polarization and single-outcome framing hampers development and implementation of policies and programs that enable equitable, durable, effective outcomes for people, biodiversity, and climate (De Oliveira Silva et al., 2021).

Such polarization may be linked to the fact that livestock production has numerous benefits and impacts for ecosystems, climate, and people (Herrero et al., 2023). Domestic ruminants are a critical part of our food systems (Herrero et al., 2023), converting low quality forage into protein and other essential nutrients while supporting livelihoods and economies (Houzer and Scoones, 2021; Schrobback et al., 2023). In some cases, livestock can help avoid conversion of natural grasslands, thereby maintaining habitats, biodiversity, and ecological processes (Gennet et al., 2017; O'Grady et al., 2024). However, they are also linked to land degradation, habitat loss, decreased water quality, and greenhouse gas (GHG) emissions (Meier et al., 2020; Bilotto et al., 2023). In particular, the contribution of livestock to tropical deforestation, biodiversity loss, and GHG emissions has spurred calls for change (Castro-Nunez et al., 2021; Taylor et al., 2016). There is also concern about increases in dietary non-communicable disease, infectious disease transmission, and animal welfare (Foley et al., 2005; Clark et al., 2020; Mehrabi et al., 2020). These issues have been amplified due to rising global meat and dairy consumption and production (FAO, 2023a,b; Harrison and Liu, 2024). With so many and such diverse outcomes from livestock production (Table A1), there is broad recognition of the need to transform systems to maximize benefits and reduce harms for people, climate and ecosystems while appreciating cultural and historical traditions underpinning the raison d'etre for livestock production systems (e.g., the FAO Global Conference on Sustainable Livestock Transformation, 2023; Burrows, 2023; Paul et al., 2020; Ryschawy et al., 2019; Scoones, 2023; Shirley and MacMillan, 2023; FAO, 2018).

However, context matters when making this transformation and livestock management practices and outcomes vary widely among and even within regions (Poore and Nemecek, 2018; Rotz et al., 2019). Practices beneficial in one location may be ineffective, unfeasible, or cause unacceptable trade-offs in others (Gravuer et al., 2019; River-a-Ferre et al., 2016; Dumont et al., 2019). Outcomes also occur at – and may have different relevance – across spatial and temporal scales. For example, GHG emissions are a global concern and often the focus of global studies (e.g., Michalk et al., 2019), yet at local scales, biodiversity, food security, or livelihoods may be most relevant and prioritized (Bilotto et al., 2023, 2024; Taylor et al., 2016). Similarly, soil carbon may take decades or more to accrue and cultural identity and values may take generations to establish or change. This complexity has hindered policy and funding initiatives aimed at promoting sustainable production systems. To advance effective solutions, there is a need to understand systems and outcomes at regional scales (Shahpari et al., 2021), grounded enough in local conditions to be relevant, yet broad enough to be generalizable for policy or funding interventions.

In response to this need, we have developed a context-based framework for livestock systems – one that incorporates an integrated view of production systems and sustainability across environmental, economic, and social and cultural dimensions – to advance the public dialogue and more concretely inform where and how the benefits of livestock production outweigh the costs for a broad view of outcomes (Fig. 1). We use a qualitative, comparative thematic analysis of case studies from diverse livestock production systems across biomes, globally, to offer insights into: 1) what contextual factors influence livestock systems and practice implementation; and 2) how contextual factors inform drivers, barriers, and enabling conditions for practice implementation. The findings highlight how incorporating context can

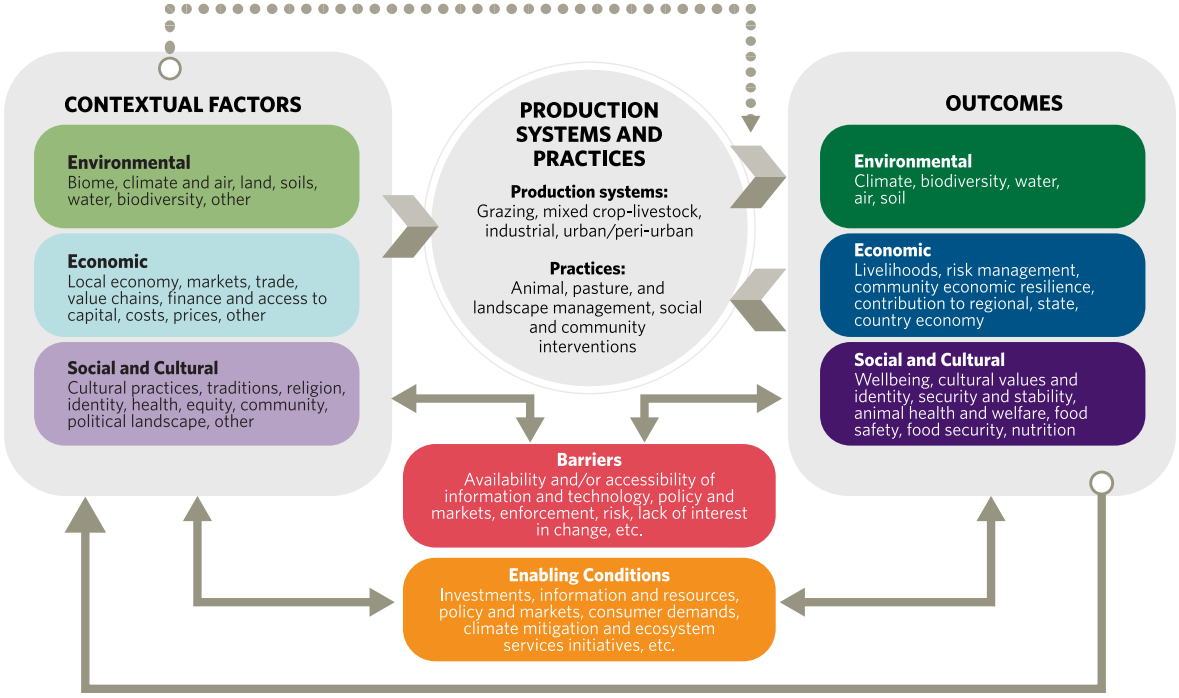

Fig. 1. Conceptual figure for understanding the role context plays in determining livestock production systems and practices, barriers and enabling conditions for practice implementation, and outcomes. Solid arrows reflect directional influence between elements of the system (e.g. contextual factors, systems and practices, barriers, enabling conditions, and outcomes) and the dotted arrow represents a modifying influence (e.g. context can determine the outcomes of different practices). Bubbles note the main examples of contextual factors, barriers, enabling conditions, and outcomes. See Tables A1, A2, and A3 for more detailed examples of outcomes, contextual factors, and specific practices, respectively.

identify effective and appropriate interventions within and across diverse production settings. We conclude by offering recommendations for integrating these findings into policy, funding, and future research aimed at increasing livestock system sustainability for people, ecosystems, and climate.

2. Methods

2.1. Approach

We used a comparative case study approach to explore the role local contextual factors play in determining current systems and potential for change. Case studies were generated from local expert knowledge informed by research, where possible, to assess the environmental, economic, social and cultural dimensions and drivers of livestock production systems and practices and their multiple outcomes, as recommended by recent studies (Harrison et al., 2021; Rivera-Ferre et al., 2016). We identified livestock production regions and developed ten case studies from a wide range of biomes, production system types, socio-political contexts, and economic contexts (e.g., low-, middle- and high-income countries). Each case study encompassed a cohesive production system existing in a specific geography with unifying characteristics. As a result, there are examples where we have multiple case studies from the same geography (e.g., we have two case studies for Eastern Africa – a pastoral case and a mixed crop-livestock case). Our case studies also do not necessarily include all livestock production in the stated geography (e.g., the Tropical Latin America case is focused on areas previously covered by forests that have been gradually cleared and replaced by introduced pastures, either partially or totally, and excludes all areas originally covered by natural grasslands, deserts, paramos, punas and other non-forest ecosystems). See Appendix A for more detail on specific case study bounds. We used the case studies to assess: 1) patterns in which contextual factors (Table A2) were particularly informative for influencing systems and practice implementation; and 2) how contextual factors inform drivers, barriers, and enabling conditions for practice implementation. We then use the case studies to explore the relative impacts of different contextual factors on current practices and potential to change (as outlined in Fig. 1).

2.2. Case study methodology

We used an in-depth semi-structured questionnaire to compile content from the literature for the case studies. The questionnaire included multiple choice and narrative/text answers broken into the following sections: Regional context, Production systems, and Practices (Appendix A). Embedded in an overall set of open-ended questions that generated qualitative responses, a structured section generated quantitative data from questions that required mostly binary yes/no responses. The answer options provided for multiple choice questions were based on existing literature (Appendix A). For example, categories of different types of knowledge are adapted from Rivera-Ferre et al. (2016), practices from Harrison et al. (2021), and barriers to implementation from Smith (2012).

Production system (Seré and Steinfeld, 1996; Notenbaert et al., 2009; Robinson et al., 2011) and biome typologies (Olson et al., 2001; Dinerstein et al., 2017) used in the questionnaire were adapted from existing classifications that are widely used by international research and policy institutions. Production systems include extensive grazing, mixed crop-livestock and industrial systems. In our case studies, grazing systems were defined as either ranching systems, in which livestock largely range freely or are moved among enclosed pastures, or pastoral systems, in which people stay with the animals to move and manage them. Mixed crop-livestock systems are those in which livestock are fed forages or crop residues grown by people, usually after it has been harvested but also in settings in which forages are planted in rotation with crops for the purposes of grazing. Finally, industrial systems are those that utilize intensive, confined animal feeding and management practices (Seré and Steinfeld, 1996; Notenbaert et al., 2009; Rivera-Ferre et al., 2016). To further characterize each production system, we included the 53 livestock production practices from a published meta-analysis that assessed the economic, environmental, and social co-benefits and trade-offs associated with emissions reduction and/or carbon sequestration interventions (Harrison et al., 2021), with additional adjustments based on a synthesis of climate mitigation practices (Rivera-Ferre et al., 2016). We added several practices (e.g., culling unproductive animals, goal setting) that the research team identified as important or were frequently recommended in at least one case study, for a total of 67 practices (Table A3).

Each case study questionnaire was completed by at least one author with direct experience working in that region and production system, and then reviewed and informed by at least one (and up to six) additional expert/s. The questionnaire was accompanied by definitions of each practice (Table A3) and the outcome variables of interest (Table A1). We developed definitions of practices and outcomes based on existing literature with expert review. In each case study questionnaire, we included supporting references that describe or contextualize aspects of livestock production, including but not limited to scientific publications related to individual practices, lifecycle analyses, or socio-political change.

2.3. Case study analysis

We conducted in-depth qualitative analysis for each individual case study and across all case studies to identify patterns. The purpose of the analysis was to understand the relationships among three domain areas (context, practices, and outcomes) within each case, and then to compare across case studies, to identify patterns and differences within each category and subcategory, as well as in relationships among those categories. We used mixed methods of parallel and sequential thematic coding and categorization to support analysis within and across cases (Creswell and Creswell, 2022). We then used deductive thematic coding, using the categories and subcategories that structure the case study questionnaire (e.g., cultural context as a category that influences production systems and feasible outcomes, and herding traditions as a specific element of context). In parallel with thematic coding, categorization of specific answers as binaries (e.g., yes/no to specific outcomes being relevant) supported cross-case comparisons. The final step in the sequential process used thematic coding and reference to the literature to generate value sets to categorize specific responses (e.g., in the questions about specific barriers to implementation, a value set could include ‘lack of financial resources’, ‘lack of technical assistance’, ‘ineffective in local climate’, etc.) to also support cross-case comparisons.

We implemented this multi-level analysis using a workbook in Excel structured to reflect the case study questionnaire that focused on organizing qualitative content within each case study to look at relationships between context and production systems, context and relevant outcomes, and context and specific practice implementation. One worksheet per case study was used. The workbook also included a sheet for cross-case comparisons, where quantitative data from the case studies directly was included (focused on livestock system types, relevant outcomes, and the presence/absence of each practice) as well as coded qualitative data that was further categorized to support systematic cross-case comparisons.

In addition to thematic coding and quantitative categorization, we undertook extensive memoing (note taking while conducting analysis) during the initial analytical process to ensure that higher-order themes that existed at the system level were not lost in the first round of detailed and domain-specific analysis. Qualitative data analysis always involves some decision-making by the researchers that lead to the final interpretation of the data and these decisions might be different if a different set of individuals undertook the analysis. However, the method

described above was structured by 1) the original data collection questionnaire (itself developed based on current literature describing livestock systems), and 2) the themes that we identified as being contested in the current evidence base related to the potential and desirability of changes in livestock systems. Thus, the analysis presented here applies existing categories and typologies related to global food systems and livestock production, triangulating between the existing literature, case study data, and ongoing expert elicitation throughout the data interpretation and writing process.

3. Results

The within-case analysis showcases the diverse economic, environmental, and social and cultural contexts in which livestock production occurs and that inform opportunities for change (Fig. 2). Some of these contextual factors are place-based and some are global (Table A2). The cross-case analysis presented in these results looks across this variation with the goal of identifying shared patterns useful for crafting policies, while maintaining understanding of the specific contexts needed for those policies to be effective. While production system type (Seré and Steinfeld, 1996; Notenbaert et al., 2009) has important implications (Rivera-Ferre et al., 2016), our case study analysis highlights that additional context is needed to understand these systems and refine typologies.

3.1. *Contextual factors are critical to understand current livestock production systems*

Combining production system type with overarching economic context emerged from the case study analysis as a useful starting way to categorize similarities and differences among individual cases. This was because local, regional, and global economic and market context, of all the contextual elements explored, is particularly fundamental to understanding existing systems and practices, as well as the enabling/constraining conditions and potential interventions for changing practices. This led to the identification of three groupings: 1) multipurpose systems in Low- and Middle-Income Countries (LMICs) (exemplified by our Tropical Latin America, Southern Africa, East Africa mixed, East African pastoral, and Tibetan Plateau of China case studies; case studies 2, 5, 6, 7, and 9); 2) commercial systems in LMICs (i.e., Tropical Latin America, Brazil East Amazon, and Southern Africa; case studies 2, 3, and 8), and 3) commercial systems found in High-Income Countries (HICs) (i.e. U.S. Great Plains, England, and Southern Australia; case studies 1, 4, and 10) (Fig. 2). While there are still considerable differences within these categories, they offer a starting point for understanding key themes among cases (Table 1) that are likely to be relevant for crafting policy or funding interventions. Beyond overarching economic and market context, some particular environmental and social and cultural contextual factors emerge as being notable for further explaining differences between individual case studies, as noted below.

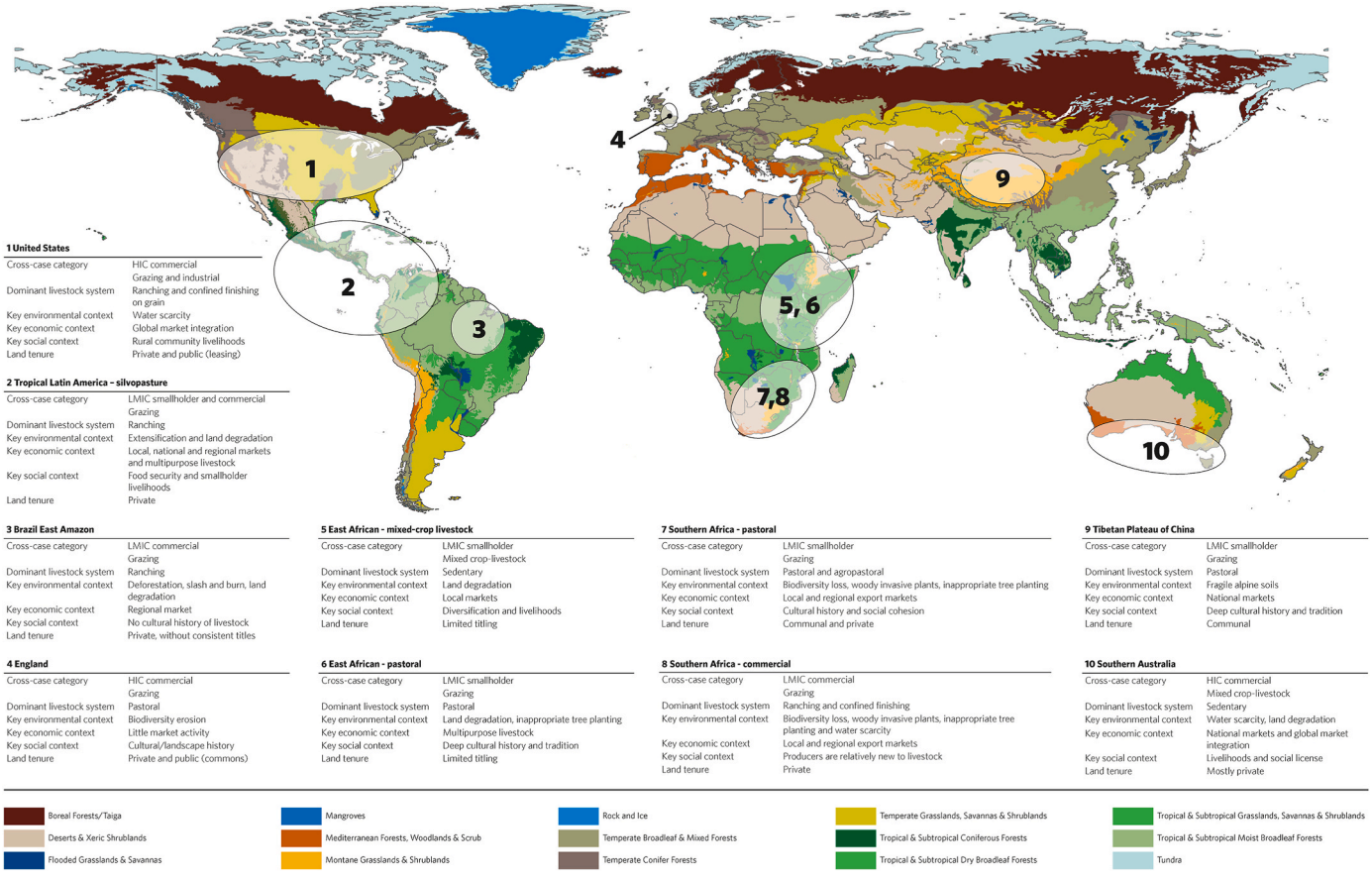

Fig. 2. Case studies. Shaded and numbered regions on the map indicate case study geographies. Corresponding text includes descriptions of the key environmental, economic, and social contextual factors at play within each case study to illustrate the diversity of these systems. Case studies were generated by and further informed by local experts in livestock production. See Appendix A for more detail. While the case studies are not comprehensive of all livestock production systems around the world, they do offer a snapshot of the diversity of systems and local contextual factors at play within livestock production systems. (Base map source: Olson et al., 2001; Dinerstein et al., 2017)

Table 1
Comparative summary of three types of livestock production categories emerging from case studies. The thematic analysis across the ten case studies led to a categorization that largely combines broad/global economic context and production system, resulting in: Smallholder multipurpose livestock systems in Low- and Middle-Income Countries (LMICs), commercial livestock systems in LMICs, and commercial livestock systems in High-Income Countries (HICs). Here we highlight key themes and commonalities within each category and compare themes across categories. In addition to these general themes, individual case studies embody much more variation even within categories, as explored in the text and Appendix A. **Bolded text** denotes shared elements across two or more categories of livestock systems (i.e., across columns).

	Smallholder multipurpose livestock systems in LMICs	Commercial livestock systems in LMICs	Commercial livestock systems in HICs
Category themes	In these systems, the theme is multifunctionality and production largely for home/local/regional use.	Main themes are that profit is a motivator of management and land managers are largely not closely connected to the land or animals in multifunctional or multigenerational ways.	Here, production systems exist with attendant access to resources, information, and technology.
Example case studies	*Tropical Latin America, Southern Africa-pastoral, East Africa-mixed, East Africa-pastoral, Tibetan Plateau of China*	*Brazil East Amazon, Tropical Latin America, Southern Africa-commercial*	*England, Southern Australia, and U.S. Great Plains*
Context	Social: Livestock is **socially and culturally embedded** in history and the present Economic: Agriculture is mostly for local markets and consumption Environmental: Tropical and temperate; diversity of natural resource contexts; negative environmental outcomes driven by economic need and lax policy enforcement Global climate change could undermine resilience	Social: Commercial production is a relatively recent phenomenon and generally not embedded in Indigenous cultural history Economic: Sub-national and national markets, with limited export opportunities Environmental: Tropical and temperate; some areas ecologically suitable for livestock, some areas ecologically unsuitable; diversity of natural resource contexts with some opportunities to increase productivity without negative impacts (possible increased emissions, also possible to limit extensification) Global market factors downscaled to regional level drive production	Social: Livestock are core to **social and cultural history** of some rural communities, but not all (not in Southern Australia) Economic: National and international markets, consolidation within supply chains Environmental: Temperate, water generally a constraint (not in England); biodiversity on working lands is seen as an opportunity Global market factors can be pull factors for change
Motivating outcomes for management	Food & nutrition security **Biodiversity** Cultural identity **Producer livelihoods** Community economic resilience **Soil health**	Contribution to national economy **Producer livelihoods** **Biodiversity** **Soil health** GHG emission reduction	Cultural identity **Producer livelihoods** GHG emissions **Biodiversity** **Soil health** Water quantity Animal welfare
Current production systems	Production practices: Mixed crop-livestock, pastoral, agropastoral Social: Mixed land tenure (communal, customary, private) Economic: Livestock for self-sufficiency and local markets Environmental: Overgrazing due to mismatch of individual land ownership and varied land tenure arrangements	Production practices: Extensive grazing, some confinement for finishing and for dairy Social: **Private land ownership, disenfranchisement of native populations** Economic: Production for urban, national and regional markets (rarely global) Environmental: Large scale production impacts water quality, deforestation through extensification (Brazil East Amazon); overgrazing is a concern when extensification is not possible or desirable (Southern Africa)	Production practices: Extensive grazing with differing use of confinement for finishing (e.g. dominant in U.S. Great Plains, not common in other cases); scale varies by location (more mixed crop-livestock in Southern Australia, pastoral in England, rangeland in U.S. Great Plains) Social: **Private land ownership, disenfranchisement of native populations** Economic: Livestock are economically viable but slim profit margins; produced for national and global markets Environmental: Grazing maintains open space and limits conversion but isn't part of a native ecosystem (except history of bison in U.S. Great Plains)
Presence and prevalence of practices	Minimal use: Animal genetics, low emissions pastures, **feed additives, manure management**, technology Moderate use: **Basic animal management**, basic pasture management, agroforestry	Minimal use: **Feed additives, manure management**, agroforestry Moderate use: Animal genetics, **basic animal management**, emissions and productivity interventions, **low emissions pastures**	Moderate use: Feed additives, emissions and productivity interventions, **low emissions pastures**, manure management (only in confinement), agroforestry, landscape management

(*continued on next page*)

Table 1 (*continued*)

	Smallholder multipurpose livestock systems in LMICs	Commercial livestock systems in LMICs	Commercial livestock systems in HICs
	Consistent use: **Social interventions, landscape management**	Consistent use: Pastureland interventions, **landscape management, social interventions** Variable use: **Technology (including forecasts, digital services, and precision ag tools)** (yes in Tropical Latin America, no in Brazil East Amazon and Southern Africa)	Consistent use: Animal genetics, animal management practices, **social interventions** Variable use: **Technology (including forecasts, digital services, and precision ag tools)** (common and broad in U.S. Great Plains, uncommon in England, emerging in Southern Australia)
Drivers of change	**Climate change mitigation and adaptation commitments**, climate investment, experiences of land degradation from overgrazing	Regulatory requirements around conservation and environmental impacts, market demand for traceability**, climate change mitigation commitments**, carbon/ecosystem services markets	Generational turnover can create opportunity for innovation, engaged consumers demanding information, strong evidence base for impacts of improved practices, **climate change mitigation commitments**
Barriers to change	Lack of financial resources for inputs, lack of access to information and technology, **lack of market incentives**, cultural history of maximizing livestock numbers	**Lack of market incentives** to improve, lack of enforcement of existing regulations	Low profit margins make risk taking hard, individualism hinders knowledge transfer, generational turnover is leading to consolidation
Enabling conditions for change	Capacity building and investment in technical assistance; Culturally appropriate training on optimizing herd management; Climate finance for inputs, technology, etc.	Structural 'sticks' from regulatory adoption and enforcement; Structural 'carrots' from market actors; investments in infrastructure for improved management, traceability	Market and consumer opportunities and demands; Regulatory enhancement in U.S.; Investment in research and development for innovative technologies; Safe-to-fail trials

3.1.1. *Economic*

Across the case studies, livestock systems exist within some market context, and the scale and primary focus of these market connections was a notable distinguisher among case studies. In many regions, domestic livestock serve multiple purposes (e.g., nutrition, fiber, fuel, currency, draft/traction, social status) and mainly support, and are responsive to, the essential needs of local communities and are not (usually) connected to national or global commercial markets (Seré and Steinfeld, 1996). In multipurpose cases, exemplified by Tropical Latin America, Eastern and Southern Africa, and the Tibetan Plateau of China, local economic objectives (food access and self-provisioning, and the use of livestock products as collateral, gifts, and insurance) guide decisions. In contrast, where livestock production is linked to national, regional, or global commercial markets, in places like the United States, Australia, and Europe, demands and dynamics differ. In commercial case studies, despite – or perhaps because of – producers' connectedness to global markets, there are typically small financial margins for producers, and supply chains are much longer. In the U.S., for example, beef cattle are often fattened before slaughter in confined operations, fed high-nutrient rations from intensively produced row crops. While U.S. beef production has long included some grain-feeding for animal nutrition and soil fertility, large-scale concentrated feeding operations, distant from grazing grounds, emerged in the 1950's driven by corn surpluses, large urban markets, and new (English) cattle breeds (Sayre, 2023). Notably, in some cases, multiple types of production systems overlap in the same geography. For example, in both Latin America and Southern Africa cases, livestock systems are bifurcated between multipurpose systems in which livestock play many economic and non-economic roles in local livelihoods, and commercial systems that have access to improved inputs and market incentives for specific practices.

3.1.2. *Environmental*

Environmental and ecological context result in very different practices and management motivations as well. Again, some of these contextual factors are hyper local, while some are more external/global drivers. Locally, the biome type or ecosystem type is a primary distinguisher between cases – particularly between places where ecosystems evolved with grazers like many native grasslands and rangelands, and places where ecosystems did not evolve with native grazing species, like many forested systems now used for pasture. For example, the native rangelands and grasslands where systems are generally extensively grazed, typically have low overall GHG footprints per unit area (Dangal et al., 2020; Scholtz et al., 2013, 2023), and if managed well may maintain habitat and biodiversity in the absence of indigenous herbivores (Metera et al., 2010; Venter et al., 2017; O'Grady et al., 2024). However, GHG emissions per unit of meat or milk are typically comparatively high due to a low forage-to-energy conversion in livestock finished at an older age and/or low or variable forage quality in native or naturalized plant species. In these systems, precipitation (and consequently forage production) is another critical contextual factor to consider. Whether livestock are finished on pasture or with grain also carries distinct impacts for ecosystems and climate. In some cases, like the U.S., the grazing phase of production is often considered a conservation compatible land use that helps avoid conversion and fragmentation of land from crops or urban development (Cameron et al., 2014). However, there are concerns over food-feed competition (Herrero et al., 2023) and livestock can cause other local environmental harms from manure management challenges, use of large amounts of water, and production of significant nutrient pollution, particularly when there is reliance on feed (Richter et al., 2020). In contrast, in places where deforestation has occurred, or there is a threat of deforestation, habitat and biodiversity loss and GHG emissions are of particular concern. For example, in some LMIC commercial cases, large expanses of land and biodiverse habitat have been converted or intensified for livestock production, significantly impacting aquatic and terrestrial species, water, soil quality, and biomass carbon stores.

3.1.3. Social and cultural

Social and cultural contextual factors are also critical to understand current livestock production systems (Shahpari et al., 2021). The role of culture and governance in livestock production were particularly emergent from the case studies. In the LMIC multipurpose case studies, ruminant animals are linked to longstanding cultural traditions and ongoing human wellbeing: they have been integral to land management, social traditions, food security, and fiber production for hundreds to thousands of years. Animals are typically owned outright by individuals or families and can represent a significant form of wealth and financial stability. However, the challenge of managing individually owned herds within communal land tenure arrangements often found in these areas can result in resource misuse (tragedy of the commons) without effective local governance systems or self-organization in effect (Ostrom et al., 1999; for specific examples, see Boonzaier et al., 1990 or Balehegn et al., 2015b). This dynamic can be exacerbated during extreme weather or climate events such as prolonged drought (Hussein et al., 2024). For instance, in pastoral systems in Eastern Africa herd size maximization is both a social and ecological adaptation to resource scarcity and variability. Farmers' traditions, beliefs, perceptions, and cultural perspectives significantly shape decisions regarding livestock management styles and investments (Mayala et al., 2019). This aligns with existing work showing how social contextual factors like gender, ethnicity, and cultural history determine what producers value as an outcome, often connected to inequities. For example, research from South Africa has shown that women prioritize use of the rangeland for fuelwood and thatching grass while men value fodder for livestock, emphasizing women's limited access to land and livestock (Bennett et al., 2023). Food and nutrition security also particularly influence management goals in smallholder multipurpose livestock systems in LMICs (e.g. Pastoralism in East and South Africa and mixed crop-livestock systems in East Africa, and livestock farming in the Tibetan Plateau of China; Tscharntke et al., 2012). The importance of cultural connection to livestock transcends case study category, aligning with work that has shown that even in capitalist systems, maintaining identity and connection to livestock and land is often a greater motivator than profit (Fernández-Giménez and Wilmer, 2024; Smith and Martin, 1972).

As a result of these economic, environmental, social and cultural context-based influences, practices may be used and considered differently across regions. For example, in the U.S., silvopasture is mainly practiced for improving productivity through reducing heat stress and diversifying products in the U.S. (Smith et al., 2022); in many places in Africa, silvopasture is beneficial for rehabilitating highly degraded cropping lands, adapting to recurrent droughts and improving livestock diets through browse supplementation (Balehegn et al., 2015a; Balehegn, 2017); and in Tropical Latin America, silvopasture can help restore and improve previously forested lands and provide cooling services (Murgueitio et al., 2011; Zeppetello et al., 2022). Conversely, silvopasture can be inappropriate such as when suggested as a way to increase tree carbon in native grass- and woodlands, misidentified as agricultural lands (Sprenkle-Hyppolite et al., 2024). Here it is ecologically inappropriate since tree planting in non-forest native areas threatens habitat for both biodiversity and cultural practices (Bond et al., 2019). Understanding the various motivations for considering and adopting certain management approaches can also inform potential for the adoption of new practices.

3.2. Contextual factors are critical to inform barriers to and opportunities for change, and the associated relevant levers for improvement

What new practices or interventions, and the scale of a proposed intervention, might be possible in the future differs by context. In particular, as shown in the three emergent categories discussed, patterns in local, regional, and global market dynamics tend to align with system drivers, barriers for change, and potential enabling conditions (Fig. 3). The cross-case analysis further highlights how considering a comprehensive suite of economic, environmental, and social and cultural factors and the ways these factors interact can not only inform the feasibility, but also the acceptability of change. Also, certain livestock production policies and investments risk unintended negative

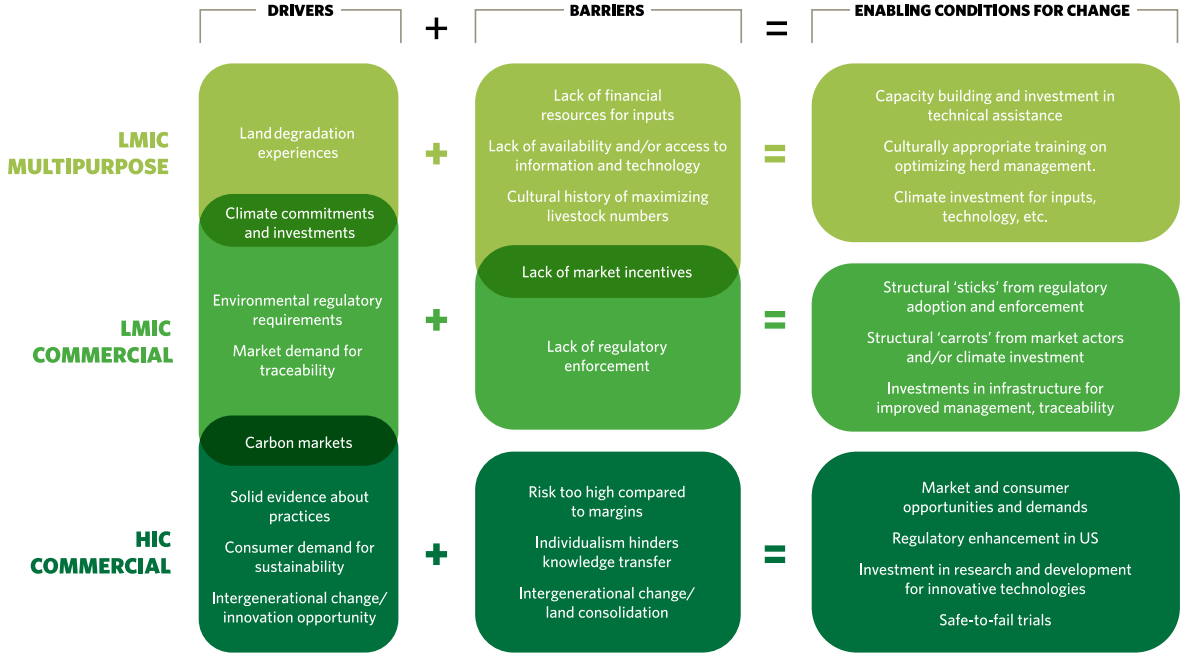

Fig. 3. Dynamics of livestock management change across case studies. The thematic analysis across the ten case studies led to a categorization that largely combines global economic- and market-based context and production system, resulting in: Smallholder multipurpose livestock systems in Low- and Middle-Income Countries (LMIC Multipurpose), commercial livestock systems in LMICs (LMIC Commercial), and commercial livestock systems in High-Income Countries (HIC Commercial). Here we highlight some of the primary themes on the drivers, barriers, and enabling conditions for change that emerged from the analysis by category, and based on the case studies included. Most are distinct to the category, but there is some overlap across categories (shown in darker green). See Table 1 for more details on the shared contextual factors for the three categories.

consequences and fail to meet diverse, place-based goals.

3.2.1. Economic

Across case studies, economic factors drive many of the barriers to change and levers for improvement (Fig. 3). For example, the lack of formal market incentives can be a barrier to change in both smallholder multipurpose livestock systems and in commercial systems in LMICs, depending on their connectivity to profit-oriented markets. For example, historically, in non-commercial and extensive settings, there has been limited deployment of some climate change mitigation practices such as improved forages, expensive feed additives, or manure management. Recently, the need to explore how existing carbon and biodiversity financing mechanisms can conserve, manage, or restore extensive rangelands while benefiting people living there has been recognized (Armani et al., 2022; Mitchell et al., 2024). There are also various policies aimed at increasing efficiency in smallholder systems via e.g., genetic improvement of livestock, the (re-)introduction of climate-resilient breeds, and improvement of market structures that value climate-sensitive practices (Mapiye et al., 2019). In commercial systems with broader market connectivity, market pull factors like consumer demand, price premiums, and market share requirements (corporate requirements for minimum standards) are all key leverage points for change. Commercial systems can also see change through regulatory push factors around land management, emissions, and environmental outcomes.

Notably, climate change mitigation commitments offer economic opportunities for change across systems, although in unique ways (Fig. 3). Climate investments from global climate agreements could create opportunities for smallholder multipurpose livestock systems in LMICs (Alemayehu et al., 2024). In Latin America, for example, where both multipurpose and commercial livestock production exists, investments in improved feeding practices through both fodder production and the use of feed additives can increase the efficiency of livestock production and provide economic and social benefits to many different types of producers (Khatri-Chhetri et al., 2021). In contrast, consumer demand for climate-related information and net-zero commitments offer clear opportunities for change in highly-connected, global market-based commercial systems. For example, in the U.S. case study, market demand could encourage new interventions such as methane-reducing feed additives or tailored genetics could be implemented in the confined feeding phase of production and controlled breeding practices, respectively. In LMIC commercial cases, there can be more resources available to enable increased production efficiency and reduced GHG emissions through vegetation management (e.g., silvopasture), feed rations, and animal husbandry practices, where and when financial incentives are available through supply chains or government programs.

3.2.2. Environmental

Our findings suggest that the ability or motivation to change management within livestock systems is often constrained by environmental factors (e.g., precipitation patterns, existing vegetation and soil conditions). Past land use and its impacts limit current practice options. For example, in the Tibetan Plateau of China and highlands of Eastern Africa, low soil quality and degraded grazing lands restrict pasture improvement or fodder cultivation; in the East Amazon region of Brazil, marginal soils degrade quickly, leading to extensification and degraded land abandonment (Müller et al., 2004); and in mixed crop-livestock systems in East Africa, aridity and limited forage necessitates pastoral management of pasturelands (Hussein et al., 2024). In HIC commercial systems, global and local environmental concerns such as climate change, resource depletion, pollution, and brush encroachment are creating interest in sustainable practices, among some actors. In England, removing livestock for biodiversity and/or climate (e.g., afforestation, rewilding) is gaining popularity in some parts of society, while facing opposition in others (Wynne-Jones et al., 2020). Furthermore, the suitability of specific production practices depends on the biome or ecoregion. For example, production systems in ecoregions without a history of ruminant grazing (e.g., forests) can sustain harm if cleared for livestock (e.g., Brazil East Amazon; Fig. 2). In these once-forested places, silvopasture can provide carbon, water, biodiversity, and economic benefits (López-Samspon and Andrade, 2024; Greene et al., 2023). In contrast, in ecoregions where herbivores were historically present, like many grasslands, livestock can fulfill an ecological niche, specifically in the absence of indigenous grazers (e.g., pastoral East and Southern Africa; Fig. 2). In these systems, silvopasture would create negative outcomes for biodiversity and carbon (Briske et al., 2024; Bond et al., 2019). Instead, livestock management can provide multiple benefits in the absence of extirpated wildlife. Other ecoregions/agro-ecological zones (e.g., England; Fig. 2) have sustained such extensive land transformation that intensive or extensive production, or even rewilding, may be suitable.

Another emerging theme from the case study analysis is the role that drought and increasing weather variability play as drivers for change. Adaptation, focusing on resilience to climate variability and land degradation, appeared as a key motivator for changing management practices, although generally only after the ecological changes had taken a toll on local communities and ecosystems. For example, it took extreme land degradation in East African and Tibetan Plateau of China systems to increase use of sustainable land management practices. As precipitation variability increasingly affects productivity in grazing systems (Sloat et al., 2018), it will be even more critical to understand the shifting environmental context for livestock production systems and how that influences which interventions and management might be beneficial, feasible, and socially acceptable now and in the future. Investing in practices that also improve a production system's resistance to climate shocks will be important, particularly in regions where reliance on livestock is fundamental for livelihoods and prosperity (Harrison, 2021).

3.2.3. Social and cultural

The case studies highlight how key social and cultural contextual factors are cross-cutting in influencing potential opportunities for change. Livestock systems with a long history of cultural embeddedness are found on multiple continents in both HICs and LMICs (to be clear, HIC livestock production can have strong cultural basis, and not all LMIC systems do, particularly in newer commercial systems in LMICs). In LMIC commercial cases considered here, most producers are small- and mid-sized operations, with sometimes unclear property rights. They are not historically embedded in local cultural and social traditions; in fact, their settlement and expansion have sometimes led to conflict with and disenfranchisement of longstanding local or Indigenous communities, such as in the East Amazon region of Brazil. In the HIC commercial cases, livestock are also embedded in multi-generational (though not Indigenous) local cultural traditions (e.g., cowboy and rodeo culture in the U.S., shepherding in the British Isles, and 'outback' rangeland production systems in Australia). Being cognizant of the cultural embeddedness of livestock production is critical for developing culturally sensitive policies that are feasible to implement, as well as in guiding funders' large investments in regional or place-based livestock projects.

Another theme across systems in various social and political contexts is the importance of land tenure in determining livestock management opportunities and barriers. In particular, a lack of certainty regarding access makes changing management practices difficult, particularly when those changes are resource- and time-intensive. For example, on the Tibetan Plateau of China, individual land titling has conflicted with a history of communal land management. Some communities have sought to adapt communal land management strategies to private livestock ownership systems, with positive ecological and financial outcomes (Gongbuzeren et al., 2016; Gongbuzeren et al., 2018) and increased adaptive capacity (Zeren et al., 2023). In East and Southern African pastoral systems, where land reform and land titling efforts have varied in their completeness, smallholders find it difficult to invest resources in

restoring degraded lands without certainty of long-term access (Balehegn, 2015; Flintan et al., 2021; Bennett et al., 2023). In the Eastern Amazon, lack of land title is the main barrier to accessing credit for small livestock farmers, but even when farmers have access, there are no sustainable credit lines specifically aimed at smallholders (Zu Ermgassen et al., 2018).

Beyond any specific contextual factor, history and cultural tradition significantly influence path dependencies for livestock production systems – both for current systems and practices and the potential for change. The 'path dependency' of history and tradition – often influenced by other contextual factors – consistently explains why more change has not occurred in particular places. This is especially true for animal management priorities (e.g., more and bigger animals signal wealth, retention of animals to maintain wealth, etc.), and traditional ecological knowledge supporting intensive but low-external input management (for example, maintaining local fodder sources but not planting improved pasture species in pastoral and mixed crop-livestock systems in Tropical Latin America and East Africa). Understanding a system's historical development is crucial for assessing potential interventions.

4. Discussion

The emerging themes in our study offer insight into the current debates on livestock and its role in the global food system (e.g., Briske et al., 2013; Godfray et al., 2018; Monbiot, 2022; Duluins and Baret, 2024), particularly in light of growing climate change, nutrition challenges and food insecurity, and equity concerns. A context-based lens that incorporates an integrated view of sustainability across multiple outcomes reveals that livestock production cannot be categorically deemed "good" or "bad", as it becomes obvious that it plays different roles, with different implications, in different places. Much of the current discussion and debate is aimed at livestock farming as a production system alone and does not consider the many social and cultural reasons – food, cultural history, draught power, economic opportunity, landscape fit, and more – that livestock systems exist. A context-based framework could advance the public dialogue to more concretely inform where and how the benefits of livestock production outweigh the costs for a broad view of outcomes.

The learnings from the case studies also further support calls to consider livestock sustainability holistically – including economic, environmental, and social and cultural outcomes – when assessing different livestock practices (Harrison et al., 2021). Indeed, our case study analysis shows that livestock management is typically motivated by at least five outcomes, with priority outcomes shifting from region to region and depending on economic, environmental, and social and cultural factors (Table 1). Incorporating multiple outcomes is particularly important as perception of a given livestock practice's value in a given place could change depending on which outcomes are assessed (e.g., just GHGs vs. GHGs, production, water, livelihoods, and cultural value together). For example, despite providing numerous critical economic, social and cultural benefits, the lower productivity and environmental costs of some smallholder systems has led some to highlight their inefficiency and need for intensification (Herrero et al., 2015). While some work has looked across multiple dimensions or outcomes (e.g., Castonguay et al., 2023; Garcia et al., 2017; Balmford et al., 2018), more research is needed to understand potential trade-offs across economic, environmental, and social and cultural considerations (Table S1) and opportunities for stacking benefits (Harrison et al., 2016; Bilotto et al., 2023). Furthermore, combining a context-based lens with an integrated understanding of livestock systems, reveals that trade-offs of different production practices, policies, or interventions differ by context, as does their degree and acceptability. As noted above, what people manage for is deeply influenced by the economic, environmental, and social and cultural dimensions of their place (Roche et al., 2015). Consequently, the acceptability of different trade-offs will similarly vary. For example, in non-commercial systems in which livestock are key sources of food and nutrition security, decreasing production below self-provisioning thresholds will likely not be politically or ethically viable. Assessing multiple outcomes across economic, environmental, and social and cultural dimensions (Table S1) at relevant scales will illuminate the potential trade-offs and benefits of different systems or practices for a given context, as well as how changes in practices could result in more benefits and fewer trade-offs across dimensions.

We suggest that a context-based lens of livestock systems combined with an integrated view of outcomes should enable better policy development, more effective investments, and more impactful research generalization. Here we offer an updated approach to categorizing livestock systems, a review of relevant outcomes, and insight into the key contextual factors that influence current systems and potential for change. We hope this framework encourages more rigorous and comprehensive assessments of which interventions might work well where. Indeed, classification systems have been used to effectively prioritize conservation actions (e.g. UNCCD WOCAT's land management practices classifications; e.g., Liniger et al., 2019). To aid in this, future research could systematically assess how livestock outcomes from different practices depend on context. For example, while there is isolated evidence of the context-dependency of outcomes in our case studies and in the literature (e.g., interventions to improve feed quality may be beneficial or not depending on genetics of the animals involved: Hatew et al., 2023; and grazing intensity can influence forage productivity differently depending on rainfall and vegetation type: McSherry and Ritchie, 2013), more work is needed to assess these rigorously at the scale of decision making. In the meantime, policymakers and investors could evaluate new interventions based on their potential impacts across multiple outcomes and the extent to which key contextual factors were considered in development of the intervention. (See Table 2 for additional ways policymakers, funders, and researchers could incorporate lessons from this work). Ultimately, widespread acceptance among key decision makers and interest in leveraging context to support a holistic suite of outcomes will be critical to realizing the benefits of this approach.

This analysis also highlights the importance of using expert-led and inclusive approaches that link local and global perspectives. To assess and inform potential livestock system transformations for people, ecosystems, and climate, inclusion of a multitude of voices and perspectives is critical (Lam et al., 2020). Even from the limited way we did this in our case – by supplementing local livestock system researcher expertise and evidence from the scientific literature with local practitioner insights – it was apparent how the multitude of perspectives created a richer and much-needed broad perspective. Indeed, one barrier to more effective action on livestock sustainability could be this disconnect between the scientific literature, which often informs policy recommendations, and practitioner experience (Njuguna et al., 2024; Roche et al., 2015). Furthermore, perspectives from place-based experts, practitioners, producers, and other local knowledge holders on the critical dynamics in livestock production will be critical to identify different practices and inform their feasibility and acceptability (Snapp et al., 2023). Going forward, policy, funding, and future research efforts should utilize local knowledge and values to gain insights into the drivers of current practices, feasibility and acceptability of shifting practices, and outcomes resulting from production in different contexts, in a non-burdensome or extractive way.

Our primary aim is to encourage broader reflection and discussion amongst decision makers on how considering context and multiple outcomes can result in more effective solutions for people, ecosystems, and climate. A different research team and/or group of case studies may have surfaced different driving contextual factors to consider. Similarly, different outcomes of interest may resonate with different audiences. We recognize that the three categories identified here – multipurpose systems in LMICs, commercial systems in LMICs, and commercial systems in HICs – are not exhaustive and do not describe all livestock production

Table 2

Summary of key findings and corresponding implications for researchers, policy makers, and funders. Implications listed include examples of potential actions or lessons decision makers could take away from findings. *Findings that emerged from the case study development process and consultation with experts and less from the case studies per se. Intervention types or actions were informed by a synthesis of multiple policy frameworks (see Table A4).

Key Findings	Implications for Researchers	Implications for Policy Makers	Implications for Funders
Case studies demonstrate the need for an integrated, context-based framework to better understand current livestock production systems.	Develop a framework and methods for interdisciplinary research that can be used across production systems and regions. Key input factors should include location/environment, production system type, socio-economic setting, and past/current practices.	Utilize local expert and practitioner knowledge to gain insights into the drivers of current practices, feasibility of shifting practices, and outcomes resulting from practices applied in different contexts. Support development of a broadly adaptable set of guidelines for identifying and assessing critical contextual factors that guide implementation of practices. Support development and use of interdisciplinary research framework and methods.	Support initiatives that leverage local expertise and experiences in livestock production systems and research/projects that assess and integrate economic, environmental, and social contextual factors. Provide project implementation guidance that ensures contextual assessments are completed before implementing changes to practices.
An integrated view of environmental, economic, and social outcomes is essential to identify solutions for sustainable livestock production that maximize benefits and minimize harms.	Document or assess a broader suite of outcome variables in new research projects, including environmental, economic, social and cultural, and market setting.	Encourage outcomes assessments and monitoring that use diverse sustainability metrics to inform decisions for optimizing positive outcomes and minimizing adverse impacts. Utilize legal, regulatory, and administrative controls to ensure integration of diverse views. Use financial support and pressure mechanisms to encourage integrating diverse perspectives and discourage overreliance on simplified commercial goals. Design effective and easier ways of integrating diverse perspectives using knowledge transfer and capacity building initiatives.	Prioritize investments in projects that promote multiple environmental, economic, and social outcomes in livestock production and that have guardrails in place to avoid tradeoffs among local values. Support interdisciplinary research that evaluates outcomes from livestock production practices holistically.
Considering local and global economic and market context alongside production system type is important for starting to identify enabling/constraining conditions and potential interventions to facilitate practice change.	Broaden scope of analysis beyond just production system type to include location, environment, production system type, past/current practices, and economic and market settings and conditions.	Develop policies that incorporate the complex interactions between production systems and economic/market dynamics. Engage globally by aligning policies with international sustainability frameworks. Participate in multi-stakeholder initiatives to define sustainability criteria. Provide financial incentives, cost-share programs, and risk management tools to encourage producers to adopt sustainable practices that may not be immediately economically viable but offer long-term sustainability benefits. Encourage knowledge transfer among producers, cooperatives, and extension services.	Support initiatives that address the multiple values and varied contexts of livestock production, including those that consider economic and market conditions.
Three context-based categories of global livestock production systems emerge and are not the same as production- system based classification. 1. LMIC, Smallholder and pastoralist, multipurpose 2. LMIC Commercial 3. HIC Commercial	**Category I (smallholder multipurpose livestock systems in LMICs)** Research on improving food, nutrition, environment, or climate outcomes in these systems should address the unique socio-cultural and ecological dynamics of these systems, including the integration of traditional knowledge with modern agricultural practices. Many past efforts of injecting resources based on single-outcome research, without considering unique local social and cultural settings, have failed. **Category II (Commercial livestock systems in LMICs)**	Support secure and equitable land tenure and rights systems. Offer incentives such as payments for ecosystem services and insurance schemes. Invest in knowledge and capacity building, establish inclusive governance structures. Adopt integrated landscape-level approaches. Support livestock practices that yield multiple benefits, e.g., including degraded land rehabilitation, improved yields, and indirect climate change mitigation, all while honoring the cultural significance of livestock for local communities.	Allocate funding towards capacity building, technical assistance, expanded delivery of veterinary services, and climate/development finance mechanisms. Invest in access to newer technologies such as feed quality and nutrition management, to improve productivity and reduce environmental degradation and improve feed production. In some places, invest in water systems or context-appropriate infrastructure.

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Table 2 (*continued*)

Key Findings	Implications for Researchers	Implications for Policy Makers	Implications for Funders
	Focus on finding ways to increase production efficiency and indirectly reduce GHG emissions through vegetation management, feed rations, additives, and animal husbandry practices in these systems. Develop practical traceability tools that ensure privacy and data sovereignty.	Implement regulatory and incentive programs for environmental conservation and animal welfare. Establish incentive programs to financially reward producers adopting higher standards in animal welfare and environmental conservation. Mandate or support transparency and traceability requirements that would ensure companies publicly report their performance in these areas. Leverage multilateral agreements with robust animal welfare and environmental protection provisions that can incentivize adoption of high standards.	Direct funding towards initiatives that support the adoption of emissions reduction technologies and biodiversity conservation in commercial livestock systems. Promote the use of technology and innovations to optimize productivity, animal health, and environmental sustainability (e.g. precision livestock farming, feed additives, improved rations, improved genetics, etc.). Facilitate knowledge exchange and collaboration among stakeholders to disseminate best practices and innovative solutions for addressing environmental and economic challenges. Focus on market tools and incentives to promote sustainable practices, e.g., traceability.
	Category III (Commercial livestock systems in HICs) Continued focus on testing of additives and feedstuffs, including use in extensive grazing settings; breeding/genetics. Tools for data and traceability. Assessing which social, economic, and environmental conditions lend themselves to uptake of promising practices with minimal tradeoffs. Develop practical traceability tools that ensure privacy and data sovereignty.	Develop policies tailored to unique socio-economic and environmental contexts. Implement regulatory measures for emissions reporting, sector-specific standards, and sustainable land use and animal welfare. Introduce market incentives like financial rewards, green procurement policies, and certification programs to encourage the adoption of low-emissions technologies and sustainable practices. Roll out voluntary traceability tools and programs with data privacy protections to enable transparent tracking of emissions, resource use, and sustainability claims across supply chains. Strengthen and leverage global climate agreements addressing environmental and animal welfare concerns, improve carbon trading viability through addressing additionality, permanence, and verifiability, and coordinate cross-border policies and standards to foster international cooperation and collective action on these critical issues.	Allocate funding towards research and development initiatives aimed at advancing technologies (see research box). Invest in research and development for improving productivity, resilience, and environmental performance (e.g., precision livestock farming, feed additives in confined settings, breeding/genetics); supportive social science; and knowledge sharing networks and advisory services. Require use of transparency/traceability tools and reporting.
Cultural embeddedness of livestock systems is not related to a region's economic status (i.e., HIC livestock production can have a strong cultural basis, and not all LMIC systems do).	Further explore how cultural factors interact with economic/market status and other contextual variables to influence livestock production practices and outcomes.	Leverage key international agreements like the UN Declaration on the Rights of Indigenous Peoples and the Convention on Biological Diversity to support culturally sensitive approaches to livestock policy. Establish policies and regulations that recognize and protect the cultural value of livestock keeping for Indigenous and local communities. Develop multilateral agreements and initiatives to facilitate the exchange of traditional livestock knowledge and practices, fund research and extension programs to support traditional livestock keepers. Provide financial incentives such as subsidies, grants, and payment for ecosystem services schemes for traditional producers.	Require a cultural contextual assessment and evaluate projects on whether relevant cultural contexts are considered in a project proposal.
History and cultural tradition play a significant role in creating path dependencies for livestock production systems.	Analyze how historical and cultural practices influence current systems and identify barriers and appropriate opportunities to change.	Recognize the importance of tradition and path dependencies in shaping current livestock practices and respecting cultural heritage, while also supporting new technologies and practices that can enable adaptation. Leverage international agreements, like the UNESCO World Heritage Convention and Intangible Cultural Heritage Convention, to enact protective cultural heritage laws. Offer incentives to preserve traditional livestock practices, establish grant programs and funding schemes to support cultural heritage initiatives in the	Support initiatives that combine traditional ecological knowledge with modern technologies for sustainable livestock production.

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Table 2 (*continued*)

Key Findings	Implications for Researchers	Implications for Policy Makers	Implications for Funders
		livestock sector and foster interdisciplinary collaboration between stakeholders to ensure holistic approaches to cultural heritage preservation and policy development.	
Ability to change livestock systems is often most constrained by environmental factors (e.g., precipitation patterns, existing vegetation and soil conditions)	Explore and articulate the specific environmental constraints that limit the ability to change practices in livestock systems in different regions. Focus on developing practices that provide simultaneous environmental and livestock productivity benefits.	Support and encourage practices appropriate to local landscape conditions. This includes standards and certification schemes.	Support projects, including standards and certification schemes, that support and encourage practices appropriate to local landscape conditions.
Disconnect between practitioner experience and scientific literature*	Draw on multiple disciplines and knowledge sources/ systems, and clearly articulate the full context of a research project, to more fully understand drivers of and barriers to change. This will help avoid misinterpretation, development of inappropriate policies or programs, and tradeoffs and inefficiencies.	Incorporate a more complete suite of context factors to avoid inappropriate application of research findings.	Complete due diligence with local practitioners and research specialists to ensure scientific findings are not inappropriately extrapolated and applied. Provide project implementation guidance that ensures local perspectives and stakeholders (herders/farmers, practitioners, etc.) are incorporated in project design and implementation.
Across smallholder systems in many different social and political contexts, land tenure/rights is a critical factor in livestock management opportunities and barriers.	Describe land tenure systems in research findings and assess how it affects enabling conditions and practices.	Develop policies that address the complexities of land tenure systems in smallholder livestock production contexts.	Invest in research and initiatives that explore the relationship between land tenure systems and livestock impacts. Provide funding for capacity building and technical assistance programs aimed at enhancing understanding and management of land tenure issues in livestock production.

systems globally. Instead, we use the 10 cases described by this research team and the analytical results described here to explore how variation in context and systems interact to generate opportunities and barriers to change. We hope that by offering this framework we spark greater dialogue and inquiry into which elements of context are critical to consider in policy, investment, and research and how doing so could lead to better outcomes for people, biodiversity, and climate.

5. Conclusion

Ruminant livestock production looks very different and leads to various economic, environmental, and social and cultural outcomes across the globe. Here, we bring together local, regional, and global perspectives to assess the role of economic, environmental, and social and cultural contextual factors in determining current systems, as well as barriers and enablers for change. We find that unique levers for change emerge for distinct contexts, with clear differences in multi-purpose systems in LMIC, commercial systems in LMIC, and commercial systems in HIC. Within these categories, ecological suitability, land health, and emerging climate change effects on precipitation greatly inform what practices are suitable or possible. We also see the need for integrated views of ruminant livestock production across multiple economic, environmental, and social and cultural outcomes that leverage local knowledge, much of which may come from viewpoints that have been and continue to be marginalized or excluded. To assess and support sustainability policies and investments in livestock systems, inclusion of diverse voices and perspectives is critical. This has likely been challenging due to a common disconnect between research and practice, the challenge of transdisciplinary work, lack of connection between global and local perspectives, and the resource intensiveness of this approach. Yet, doing so will be necessary to increase the likelihood that solutions are feasible in a given context and maximize benefits for people and nature. For policymakers, funders, and researchers, the refined framework we offer provides a clearer path to shifting livestock systems to be more sustainable across economic, environmental, and social and cultural dimensions, with solutions tailored to unique contexts.

CRediT authorship contribution statement

Clare E. Kazanski: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Mulubhran Balehegn:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation. **Kristal Jones:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis. **Harriet Bartlett:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Alicia Calle:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Edenise Garcia:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Heidi-Jayne Hawkins:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Dianne Mayberry:** Writing – review & editing, Writing – original draft, Investigation. **Eve McDonald-Madden:** Writing – review & editing, Writing – original draft, Conceptualization. **Wilfred O. Odadi:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Jessica Zionts:** Writing – review & editing, Writing – original draft, Investigation. **Michael Clark:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Tara Garnett:** Writing – review & editing, Methodology, Conceptualization. **Mario Herrero:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Hannah VanZanten:** Writing – review & editing, Methodology, Conceptualization. **John Ritten:** Writing – review & editing, Writing – original draft, Investigation. **Giovanni Mallmann:** Writing – review & editing, Writing – original draft. **Matthew Tom Harrison:** Writing – review & editing, Writing – original draft, Methodology. **Deborah Bossio:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Sasha Gennet:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2025.100840.

Data availability

The multi-level analysis is available as an Excel file upon request.

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