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Resilient livestock supply chains in Pakistan: adaptive strategies for climate-smart agriculture and food security

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The agri-livestock sector in Pakistan is of critical interest to the socioeconomic fabric of rural areas and is currently facing the risk of systemic vulnerabilities being exacerbated by climate change. The study is part of the doctoral thesis for performance evaluation of a public sector entity under environmental factors. In this paper, we will discuss adaptive measures toward climate-smart agriculture (CSA) in resilient livestock supply chains, based on a study of agri-livestock public sector organizations. In the study, we combine institutional records, interviews of key players, and thematic analysis research to extrapolate on the main facilitators and barriers to resilience. In the study, we conclude that structural gaps, such as unstructured logistics, lacking governance, insufficient financial inclusion, and gender discrimination, continue to exist; nevertheless, new innovations, such as silage production, solarized cool chain, and digital tracing systems, are developing. As much as interventions by public sector organizations can have local gains, resilience at the system level is limited by misaligning policies, institutional impediments, and inadequate investments in the climate-resistant infrastructure. In the paper, it is indicated that the adaptive capacity of the livestock sector in Pakistan requires a system-wide, coordinated, equity-based recalibration that needs to incorporate CSA principles in line with market access, public-private partnership (PPP), and inclusive governance. The policy recommendations underline the importance of integrated national policies, flexible investment in infrastructure, gender mainstreaming, and financial de-risking procedures to preserve food security and rural livelihoods when faced with intensifying climate risks.

KEYWORDS

climate-smart agriculture, resilient livestock, supply chain governance, public sector organizations, gender inclusion, climate adaptation

1 Introduction

The agri-livestock sector is central to sustaining the socioeconomic fabric in the rural Pakistan, and it is a key foundation to national food security, livelihoods, and economic growth in rural Pakistan (Shahbaz et al., 2022; Sohaib and Jamil, 2017). Nevertheless, agri-livestock supply chains which encompass production and processing, distribution, and access to markets are still susceptible to a myriad of systemic issues, including climate variability, inadequate infrastructure, inconsistency in policies, and poor integration into value chains. Such difficulties disrupt productivity, which not only undermines the profitability but also poses a threat to the ability of the sector to withstand shock in the

TABLE 1 Key elements of the framework.

Factor	Strategic role
CSA-driven farm practices	Climate-resilient breeds, improved fodder, water efficiency, and herd management
Cold chain and infrastructure	Solar-powered storage, mobile processing, and temperature-controlled transport
Institutional governance	Policy consistency, delegation of roles, monitoring, and evaluation systems
Digital innovation	Remote sensing, blockchain for traceability, and early warning systems
Financial and market access	Microcredit, insurance, cooperative marketing, and halal certification for exports
Stakeholder integration	Public–private partnerships, farmer cooperatives, and value chain alliances

future (Azadi et al., 2022). The key elements of the proposed framework are summarized in Table 1.

Over the past years, the livelihood of livestock systems has continued to become more susceptible due to the increasing effects of climate change (Khan et al., 2024; Sargani et al., 2025). Randomized weather conditions, excessive droughts, heat pressures, illness breakouts, and access to food are growing to interfere with animal health, the production cycle, and market balance (Vatsa et al., 2023). The World Bank and FAO have identified South Asia, with the participation of its realities, including Pakistan, as among the most climate-threatened areas worldwide, and noted that more in-depth livestock-reliant communities experience excessively abundant blemish (Melgar et al., 2025). This fact necessitates a redesigning of the way supply chains are organized, managed, and governed so as to guarantee continuity adaptability with regard to long-term sustainability (Vatsa et al., 2023).

The traditional supply chains in the Pakistani livestock industry are highly linear, disjointed, and input-driven, with hardly any facet of risk management or climate-resilient principles being incorporated (Usman et al., 2023). Furthermore, the access of low-income farmers (termed smallholder farmers and comprising the core of this industry) to the market-based solutions, technological advances, and institutional solutions and support systems that would otherwise enhance their adaptive capacity are usually not available (Zaurez Afshar and Hussain Shah, 2025). Therefore, to develop resilient livestock supply chains, there is a need to abandon the current patterns and turn to climate-smart agriculture (CSA) approaches, which incorporate sustainability, equity, and innovativeness into every supply chain point (Faisal et al., 2020; Khan et al., 2024).

FAO defines climate-smart agriculture as the policy of achieving a win of all the three aspects: raise agricultural productivity, resilience to climate change, and minimize greenhouse gas emissions. To use case on livestock, this framework involves the interventions that include drought-resistant fodder production, better animal breeds, precise feeding, disease surveillance networks, cold chain investment, and mobile processing facilities (Melgar et al., 2025). Nevertheless, there has been unevenness in practices of these strategies in Pakistan, and those practices are subject to less study, especially as regards a systems approach that involves interdependencies among actors, institutions, and environmental factors (Abid et al., 2017; Sargani et al., 2025).

The paper is dedicated to addressing that gap by delving in adaptive mechanisms to the establishment of resilient livestock supply chains in Pakistan in the context of climate-smart agriculture. It documents the institutional processes, technologies that facilitate such resilience-building processes, and policy frameworks that can facilitate resilience-building. Based on data point production, policy research, and comparative case-based knowledge contributions, in the paper, we provide a multidimensional guide to policymakers, development players, and stakeholders in the private sector. Finally, it will also help contribute to the greater debate surrounding climate-resilient food systems and the development of an adaptive agri-livestock supply chain.

2 Theoretical background

2.1 Theoretical underpinnings of supply chain resilience

The paradigm of supply chain resiliency has become a key term in the operation-related and sustainability literature in the current context. Resilience refers to the adaptive capacity of an entity to respond and recover disruptions and continue its operation and control (Afshar and Hussain Shah, 2025). With reference to the agri-livestock systems, resilience is more than logistic agility but includes environmental, economic, and social flexibility. The ecological resilience concept about the ability of the system to absorb a shock without a relapse into a stable alternative state has been utilized to design adaptive supply chains capable of responding to shocks such as climate change, pandemics, and geopolitical instabilities (Do et al., 2022; Singh and Singh, 2019).

2.2 Climate change and livestock supply chains

Livestock systems are both the contributors and victims of climate change. Major studies indicate that the industry contributes to the global greenhouse gases (GHGs) due to enteric fermentation, the management of manure, and land-use change (Kikstra et al., 2022). In Pakistan, where the majority of livestock is primarily raised in mixed crop–livestock or pastoral production

systems, the negative impact of the climate change is associated with reduced access to feed, increased disease levels, water shortages, and diminishing output of livestock at the family level (Abid et al., 2017; Usman et al., 2023). Irrespective of these weaknesses, the concept of climate-resilient livestock development has seldom been exploited in the national policy process and local adaptation planning.

2.3 Climate-smart agriculture and the livestock nexus

Changes in climatic conditions present a real challenge to sustainability in livestock production, and one practical solution to this problem is CSA. CSA involves three pinnacles, which are (i) increasing productivity, (ii) creating resilience and adaptation, and (iii) cutting down emission. These aims are set in practice in the livestock environment through combined measures of better forage, climate-resistant breeds, rotational grazing, cold chains supported by solar energy, and animal health being tracked with the assistance of technology (Melgar et al., 2025; Vatsa et al., 2023). The effective implementation, however, is conditional to enabling institutions, coordination of stakeholders, and building capacity at the farm level, all of which do not exist at the required levels in Pakistan in terms of policy and allocation of resources.

2.4 Supply chain fragmentation in Pakistan's livestock sector

The Pakistani livestock supply chain can be characterized by the informal chain of intermediaries in a long supply chain, low access to formal markets, underdeveloped cold stores and transport, and low co-ordination between up- and downstream players (Imran et al., 2018; Khan et al., 2024). Such losses translate to low post-harvest outcomes, subjugated farmgate prices, and the inability to compete in the foreign markets. In addition, smallholder farmers, the owners of more than 80 percent of livestock, rarely have institutional connections or financial tools to exploit climate-smart technology or climate-proof the supply chain (Zaureh and Shah, 2025). The lack of the integrated approach to the value chain compromises the performance of the economy and the stability of the whole system.

2.5 Institutional and governance dimensions

In Pakistan, the management of livestock supply chains is decentralized into federal, provincial, and district levels and tends to create with uncoordinated policy formulation and inconsistent policy enforcement. The absence of any national policy on the livestock supply chain also discourages systemic change. According to international best practices, effective multi-stakeholder space, that is, producer cooperatives, value chain alliance, and public-private partnerships (PPPs), can contribute to greater resilience (Usman et al., 2023). However, they have a very small penetration in Pakistan because of institutional inertia, regulatory restrictions, and ineffective culture of collaboration (Khan et al., 2024).

2.6 Gaps in the existing literature

Although, internationally, the literature has expanded in more detail regarding the link between CSA and supply chain resilience, there has been little empirical research of any sort in this regard in Pakistan, particularly through a systems thinking perspective (Ahmad et al., 2024; Nadeem et al., 2024). The available pieces of the literature are either sectorally segmented (divided among feed, health, or marketing in isolation) or do not reflect a holistic approach to resilience. In addition, there are a minimal number of studies that provide applicable policy pathways of incorporating climate-smart livestock practices (Kamal et al., 2022; Sardar et al., 2021).

The literature reviewed indicates the fact that the multidimensional perspective on improving the resilience of livestock supply chains should be applied to Pakistan. It is crucial to incorporate climate-smart agriculture into a connected supply chain structure where it is backed by facilitating mechanisms of governance and institutions to guarantee the food security, rural livelihood, and ecological sustainability (Imran et al., 2018; Usman, 2024). The following section continues these insights with the conceptual framework behind this study.

3 Conceptual framework

3.1 Framing the problem

The conceptual framework followed in the study is based on three interdependent areas, namely, supply chain resilience theory, CSA, and systems thinking in agri-value chains. All these threads lead together in terms of the systemic exposure of the livestock supply chain of Pakistan to the growing risks of climatic change.

The model presumes that making the livestock supply chain resilience is an integrative practice, which involves four fundamental levels of adaptive strategies:

1. Farm-level production
2. Logistics and infrastructure
3. Support institutional and governance
4. Financial mechanisms and market linkages

Every level is considered the lever and the constraint, depending on the volume of resource distribution, policy attention, and coordination between the stakeholders. The model is integrated to the concept of climate-smart agriculture and focuses on feedback loop, interdependence, and enabling conditions to ensure long-term resilience and food security.

All the elements promote resilience on a system-wide level, with CSA as the central composite and policy/institutional coherence as the primary facilitator.

3.2 Application of the framework

The operationalization of this conceptual model comprises an identification of a multidimensional perspective that acknowledges the following:

- Temporal resilience (empowering recently to recover quickly or in the medium term to adapt to an event)
- Functional resilience (reorganizers, innovators, and learners)
- Equity and inclusivity, especially where smallholder farmers and women in livestock systems are concerned

The role of policy and investment agreement is also emphasized, particularly in a devolved governance system in Pakistan, such as that enacted after the 18th Amendment, where provinces have the key responsibility of implementing agricultural systems.

4 Methodology

4.1 Research design

The research study consists of a qualitative exploratory research design based on a case study approach in examining the adaptive mechanism of a livestock supply chain in Pakistan through the prism of CSA. The qualitative design is able to support an in-depth investigation of institutional processes, actor patterns, infrastructure deficits, and policy structures through the complex, systemic, and context-specific postulation of resilience in agri-livestock systems (Creswell and Creswell, 2018; Palaganas et al., 2017).

The study is carried out in a constructivist paradigm which unconsciously considered various realities existing within the ecological terrains, contexts of governance, and market structures of Pakistan. This paradigm facilitates a versatile approach applicable to policy-based, solution-approach research in the developing economies.

4.2 Case selection and sampling strategy

Purposeful selection based on both geographical and ecological variability resulted in the occurrence of three globally dispersed cases of livestock supply chains as representatives of distinct vulnerability and adaptive capacity:

1. Punjab (Central Pakistan): this region has been characterized by high density of livestock, inadequate cold chain facility, and some level of adoption of CSA.
2. Sindh (Southern Pakistan): climate-vulnerable place where droughts are frequent and the political structure is divided.
3. Khyber Pakhtunkhwa (Northern Pakistan): mountainous geography, pastoralism, and unformalized markets.

The major stakeholders were identified by using purposive sampling in each region (including):

- Smallholder livestock farmers
- Veterinary service providers
- Cold chain logistic administrators
- The officials of the livestock departments and agriculture extension
- Officials of donor-funded CSA programs and NGOs
- Value chain players including meat exporters

Within the framework of the study, 32 semi-structured interviews and 6 focus group discussions (FGDs) among the respondents were conducted in January–April 2025.

4.3 Data collection methods

The study utilized several data collection techniques so that it might be triangulated effectively:

- Semi-structured interviews: to elicit first-hand experiences, coping patterns, and institutional problems.
- Focus group interviews: to learn community-based perceptions, community-based innovations, and gender effects.
- Review of documents: various documents such as policy reports, CSA guides, provincial plans of livestock, and donor program evaluations have been reviewed.
- Field survey: some visits to the field were made to check conditions of the infrastructure, animal health management, and market dynamics.

The interviews were conducted in Urdu or local languages and subsequently translated to English. Research ethical guidelines were strictly adhered to while conducting interviews.

4.4 Data analysis technique

Thematic content analysis was used to analyze data on the six-phase model strategic framework, which entails familiarity with data, initial coding, identification of themes, theme reviewing, definition and naming of themes, and final report (Braun and Clarke, 2022). The themes identified were charted into the conceptual framework, especially on climate-smart adaptation practice, institutional enablers and constraints, resilience mechanisms, and market and logistics innovations. A matrix coding query was also performed to find out the co-occurrences and relationships among the regions, adaptation practices, and governance arrangements.

4.5 Trustworthiness and validity

A number of qualitative validation methods were applied to guarantee the credibility, transferability, dependability, and confirmability of the findings. Member checking was completed by sending interview summaries to the respondents to verify validity, and peer debriefing was made in meetings with CSA professionals and scholars in the field of supply chains. The cross-verification of data with the help of interviews, documents, and field observations was used to make the triangulation. In addition, to ensure better transparency and traceability during the research process, all field notes, coding activities, and analytical memos were well documented.

4.6 Limitations

The qualitative nature of the study and its geographical reach are limited and can hinder the extent to which the study findings could be generalized to the entire Pakistani regions. Nevertheless, the level of analysis provides transplantable knowledge that can be used to develop policies, transform institutions, and make resilience plans in comparable agro-ecological settings.

5 Findings

This part includes major empirical evidence of 32 semi-structured interviews, 6 focus group discussions, observations in the field, and reviews of the documents carried across the province of Punjab, Sindh, and Khyber Pakhtunkhwa. Using thematic coding, the analysis reveals nine major themes as a centerpiece; they are identified, all of which demonstrate dynamics of the structural or adaptive way the livestock supply chain operates in Pakistan under climate pressure. These results describe local and global phenomena.

5.1 Limited climate-smart farming practices

Practices of CSA by farmers in the livestock sector are in their infancy. Although awareness of drought, heat stress, and fodder crop scarcity as risk factors are increasing, there is a gap in a systematic adaptive practice. Certain progressive farmers in Punjab have started to cut and preserve silage and fodder but provide cost and knowledge as hindrances to their greater widespread adoption. In KP, only indigenous breed use is considered an informal method of resilience even though systematic breeding schemes are nonexistent. In all territories, no single-inclusive CSA models that integrate climate-resistant fodder, economics, and water efficiency management measures are present.

5.2 Infrastructure limitations

The lack of a reliable infrastructure of cold chains was cited as one of the most common problems in all the stakeholder groups. The losses in terms of meat spoilage due to the lack of cold storage facilities and in the absence of refrigerated transport are persistent to both Punjab and Sindh. Exporters pointed out that poor infrastructure not only impedes the retention of domestic value but also compromises the conformity of international halal and hygiene standards. Modern abattoirs and solar-powered chilling machines were also called out as possible solutions although utilization of this sort is not readily observed and is donor-dependent. There is still a lack in public investment in climate-resilient infrastructure.

5.3 Institutional fragmentation

One of the themes common to all interviews was that the governing structure of livestock was fragmented. The stakeholders outlined duplication between the provincial and

federal levels, indistinct mandates, and lack of consistency in the policies of implementation. When CSA strategies exist, they are frequently implemented independently of overall supply chain planning. There was also low coordination between departments, as reported by extension officers, and the unpredictable nature of the policy framework when making an investment, as expressed by the private sector stakeholders. This form of fragmentation in governance is a barrier to coordination both in the vertical dimension (among government levels) and also the horizontal dimension (among supply chain players).

5.4 Digital innovation: high potential, low penetration

The use of digital technologies to develop resilience is gaining its popularity, but it is still implemented on a mixed basis. Animal health alert systems via SMS were successful in some NGOs of KP. Nevertheless, the rural Sindh and southern Punjab farmers stated the low awareness and access to such tools. Traceability mechanism, remote sensing to identify climate alerts, and mobile veterinary services were either at pilot phases or nonexistent. The most common obstacles to scale were digital illiteracy, connectivity, and training.

5.5 Market volatility and middleman dependency

Farmers, in all regions, were found to have high exposures to the volatility of price and to dependence on informal middlemen. The lack of well-organized markets, grading, and farmer cooperatives reduces bargaining power and keeps the incomes of producers down. Even in the comparatively commercialized regions of Punjab, the farmers were concerned with the absence of the transparency in pricing-setting and differentiation by quality. Exporters observed that in the absence of traceability of supply chains and quality certificates, Pakistan would have problem in accessing high-value international markets.

5.6 Inadequate financial access

Capital to make climate-resilient investments is grossly constrained. A majority of farmers complained that they were unable to access credit because of collaterals and deficiency in documentary records. No respondent has indicated access to livestock insurance, weather-based insurance, and other methods of risk transfer. Donor agencies affirmed that the current existing models of micro-finance are ill suited to livestock life cycles and seldom included the phenomenon of climate risks. Such financial exclusion has a direct negative effect on adaptive capacity.

5.7 Gendered roles and structural exclusion

The conduct of focus group discussions helped establish the critical position of women in livestock management, especially in the

management of small ruminants (management of small ruminants, feeding, and milking), and highlighted their exclusion from extension services and training programs. In both Sindh and KP, women said that they had no access to veterinary services, to decision-making forums, and to markets. Even though they contribute labor and have knowledge regarding livestock activities, they have no formal representation in resilience planning, hence compromising the adaptive capacity of livestock systems at household levels.

5.8 Weak extension services

The livestock extension service in the three provinces was reported to be under-resourced and reactive. Officers reported minimal mobility, outstanding demands of services, and insufficient logistical support. On climate-smart interventions, farmers complained of few visits, low levels of responsiveness, and minimal technical advice. These gaps were occasionally covered up by donor-backed programs, which, however, were not embedded in permanent processes of delivering public services. Institutionalization of CSA knowledge within the extension network is also a key limitation.

5.9 Untapped partnership potential

The private sector players were also willing to co-invest in cold chains, animal welfare technologies, and export standard facilities with policy predictability and fiscal support. Nevertheless, there are no PPP frames or de-risking tools in the public institutions that could encourage such investment. Several stakeholders referred to the existence or rather a lack of trust between the government and the private players, which, coupled by the lack of unity in the enforcement of the contracts and the uncertainty in regulation, among other things, defined a lack of trust between the two sides. This restricts the industry to coordinate individually in response to climatic disruptions.

The results indicate that livestock supply chain resilience in Pakistan is limited by both structural bottleneck (infrastructure, finance, and policy) and functional bottleneck (coordination, capacity, and trust). There are isolated shows of innovation; however, the latter has not been systematically implemented and scaled. The long-standing continuation of the fragmented nature of governance and marginalization of key players (particularly women and smallholders), on the one hand, and under-investment in CSA-aligned infrastructure, on the other hand, indicates a strong necessity to introduce a coherent, inclusive, and system-based approach to resilience-building in the sector.

6 Discussion

In this paper, value is added to the current debate of climatically vulnerable economies on livestock supply chain resilience to synthesize the grounded evidence in Pakistan within the integrated framework of CSA. The results indicate that although interest in climate risks is increasing, practical action in resilience-

building is, in practice, sporadic, unwieldy, and not well backed by structural facilities or institutional comprehensiveness. This part explains these results as part of the theory of resilience, the principles of CSA, and global experience, proposing a channel of practical and policy change.

6.1 Resilience and institutional fragmentation

Resilience in agri-livestock systems is typically being restrained by the very fact that it merely represents the capacity of the farmers to deal with shocks by making farm-level adaptations of an incremental nature. This study does not, however, entirely concur with the arguments made by Walker and Christopher that resilience should be viewed as a property of the system, which is defined by “feedback loops, cross-scale linkages, and adaptive governance” (Christopher et al., 2004; Walker et al., 2004). The lack of adaptation of CSA practices in Pakistan is not only a gap in awareness but also a much deeper problem of a systemic nature related to lacking access to finance, poor extension services, poor infrastructure, and institutional continuity. As such, resilience should be redefined as a multilevel concept, which requires distributable capability at state, market, and civil society levels. Another problem that makes this more complicated is the governance fragmentation problem and institutional inertia. Devolution of agricultural power and having a separate authority under the 18th Amendment, although intended to increase provincial responsiveness, has contributed to a proliferation of parallel administrative systems, inability to coordinate across vertical lines, and duplication of policies, as noted among the disadvantages of decentralized governance (Shahbaz et al., 2022; Usman et al., 2023). Without a unified national system of working toward common standards, investment processes, and accountability processes among provinces, CSA initiatives remain incoherent and non-sustainable. In line with this, institutional resilience needs to be considered a key policy target to meet the objective of adapting over time in a sustainable manner.

6.2 Structural constraint on resilience

The physical infrastructure, especially the cold chains and off-grid energy solutions, is very poor, which is a crucial constraint on supply chain resilience. The supply chain of livestock in Pakistan has been faced with excessive post-harvest losses, poor value addition, and perishability risks, which are attributed to poor chilling, processing, and storage issues. Such a disparity is bigger than a logistics problem; it is a failure to adapt changing climates. Direct investment on climate-resilient infrastructure (solar-powered chillers and mobile processing units) can alter the vulnerability picture of the entire supply chains, as demonstrated in other similar situations such as Kenya and Vietnam (Naveen et al., 2024; Usman, 2024). The climate finance strategy of Pakistan thus needs to enlarge beyond its scope of mitigation to include adaptive livestock system infrastructure.

6.3 Digital innovations: Unrealized potential

Information and communication tools have potential progressive effects on real-time risk management, veterinary care, market connections, and traceability (Dovbischuk, 2022). However, in this paper, it is indicated that there exists a disconnection between pilot innovation and the scale of systems. Even though cases of SMS-based alerting and mobile veterinary exist, technical challenges such as digital literacy, poor infrastructure, and poor institutionalization hinder their adoptability. This resonates with that of the failure of innovation diffusion, as explained in the innovation diffusion theory by Rogers. Digital resilience has to insinuate itself where people are, so Pakistan has to transition well beyond fragmented, donor-dominated pilots to a national digital livestock strategy founded on collaboration with both the private and the public sectors, a universal access ethic, and service anchoring.

6.4 Gendered exclusion in resilience planning

The study of resilience has been acknowledging the importance of gender inclusion as the fundamental unit of adaptive capacity (Walker et al., 2004). Nevertheless, the livestock systems in Pakistan are structurally invisible to the role of women in livestock, animal care, and informal marketing. Their non-representation in the training, credit, and policy formulation makes the resilience, at the house level, weak and restricts legacy of adaptive approaches to the new generations. It is not only equitable but also important to have a gender-responsive lens implemented in CSA practice, including gender-specific extension services, extension credit to women livestock keepers, and woman inclusion in farmer organizations.

6.5 Financial inclusion and risk transfer gaps

Livestock systems have little climate risk-focused insurance, and financial instruments are not adapted to the reality of the sector. This seriously compromises the capacity of the smallholders to make adaptive technology investments or shock recovery (Khan et al., 2024). A failure to transfer risk appears to be structural as there is no livestock insurance, concessional lending, and weather-indexed finance instruments. Countries such as Ethiopia and India have managed to test the advantage of community-based livestock insurance systems and input-credit-insurance packages. Pakistan has to contextualize such models to its socioeconomic setup to unleash CSA adoption in scale.

6.6 Resilience framework

Collectively, the findings highlight the importance of transitioning a system-based resilience framework to siloes livestock interventions. This entails the following:

- Inter-ministerial policy integration regarding CSA, food security, livestock, and climatic policy.

- Enhanced electronic networks that are connected with provision of public service.
- Gender-integrated capacity-building and the finance introduction.
- Elaborating a replication mechanism of PPPs through definite risk-sharing mechanisms.

The approach is compatible with the international frameworks annotated as the FAO Climate-Smart Livestock Agenda and the African Union Livestock Development Strategy, through which the concept of integrated governance, inclusive innovation, and system thinking are prioritized as resilience pillars.

The strength of the livestock supply chain in Pakistan cannot be promoted by having single interventions. It has to undergo a structural re-balancing, in terms of policy, institutional, financial, and technological aspects, rooted in the principles of climate smartness and based on local conditions. In the study, we provide a practical model, an empirical basis to guide national resilience policies, donor coordination, and future research in understanding cognitions of system transitions in the climate-vulnerable economies of the agri-food sector.

7 Conclusion and policy recommendations

7.1 Conclusion

In this paper, we have assessed the structural, institutional, and operational aspects of resilience in the Pakistan livestock supply chain in the context of CSA. The study revealed, with multi-site qualitative inquiry, many intertwined issues that cut across a wide spectrum of interdependent issues: cold chain inadequacy, the fragmented nature of governance, the digital divide to market volatility, and the marginalization of gender. Although a few individual stakeholders have adopted the adaptive practice at the local level, the overall supply chain is still at a high risk of climate-related disruption, policy inconsistency, and infrastructural stagnation.

An important contribution of the work is to give systematic structure to resilience as not only a farm-level property but also a product of coherent policy, inclusive institutions, responsive markets, and adaptive infrastructure. These results support the idea that the current fragmented and reactive interventions should be changed with the coordinated national strategy, consistent with CSA principles, equality, and system integration.

Finally, the issue of building resilience in the livestock sector of Pakistan is, and has to be, both a technical and a governance issue and a developmental need specifically because of the importance of the sector in the food security, rural livelihoods, and economic stability.

7.2 Policy recommendations

Based on the study's empirical findings and conceptual framework, the following policy recommendations are proposed:

7.2.1 Climate-smart livestock strategy

Development of a harmonized National Climate-Smart Livestock Strategy to ensure consistency between federal and provincial actions is required to create systemic resilience in the livestock sector of Pakistan. This plan ought to incorporate CSA concepts into livestock planning, budgeting, and performance monitoring systems in all administrative levels. It should also incorporate the resilience indicators in the national livestock policy, with good cross-sectoral connections to the larger climate adaptation, energy efficiency, and food security policies. They would allow coherence, accountability, and long-term investment planning, which is essential to the mainstreaming of CSA in the various agro-ecological zones through a coordinated policy framework.

7.2.2 Infrastructure, cold chains, and digital innovation

The livestock value chain resiliency relies on strong infrastructure and the involvement of technology. To enhance post-harvest handling and minimize losses, public and blended finance models should follow the investment in off-grid and solar-powered cold storage facilities and modern slaughtering facilities, along with the creation of decentralized processing centers. The provincial governments should set up infrastructure funds that will be supported by incentives to draw in private capitals to develop climate-resistant systems of logistics and supply chains. At the same time, the national digital livestock platform is supposed to be introduced for consolidating the disease surveillance, weather notifications, market access, and traceability tools. Digital literacy programs and smart phone distribution programs should also be scaled in rural settings, and in particular, it should empower women and the youth within livestock-based households to have equity in accessibility.

7.2.3 Gender equity and financial inclusion

To deliver wide-spread resilience, gender and the social inclusion need to be incorporated into the foundations of CSA. Gender-responsive budgeting ought to be incorporated by all livestock development programs, and outcome monitoring should be done using gender-disaggregated indicators. Cooperative farming promoted by women, integrated extension service regimes, and access for both men and women to credit, training, and markets should become key functions of national and provincial programs. At the same time, financial inclusion can be enhanced by livestock-specific insurance covers, such as index-based climate risk insurance, and by increasing concessional credit, guarantee facilities, and revolving the quality of finance facilities to concessional loans targeting smallholder investments in CSA technologies.

7.2.4 Institutional capacity and extension services

The institutional capacity development is meant to play a central role in delivering CSA interventions. The extension systems of livestock should be restructured to encourage the transfer of climate-smart practices, participatory planning, and government accountability. This will involve creation and implementation of an outfit of educated para-veterinary workers to attend to areas that are remote and underserved. The institutional strengthening of provincial departments, research organizations, and service delivery organizations should also be addressed through capacity-

building to increase their coordination, technical delivery, and sensitivity to emerging climate risks.

7.2.5 Mobilizing innovation and public–private partnerships for resilience

The key to the rapid boost of the livestock industry resilience is the innovation and partnering practices. A formalized system of PPP is to be established to create privately financed investments in CSA-aligned infrastructure, innovation, and input markets. Governments should be aggressive in de-risking the activity of private investment in terms of co-financing agreements, policy guarantees, as well as through fiscal incentives. At the same time, a Resilience Innovation Fund is proposed to fund pilot projects, scaling, and evaluation of CSA-based solutions. This fund must encompass dedicated windows of youth- and women-led innovation projects that propose scalable solutions in the climate-resilient management of livestock, thereby supporting a diversified and inclusive innovation system.

7.3 Concluding reflection

Uncertainty about the climate provides the Pakistan livestock sector with a point of juncture. Resilience will not emerge from just one good practice here and there; it will come from considered thought, deliberate action, and inclusive and coordinated efforts across the entire supply chain virtual. In this paper, we present a plan to transition from vulnerability to resilience by harmonizing infrastructure, innovation, institutions, and inclusion into a harmonious climate-smart vision.

8 Declaration

- Ethics approval and consent to participate: this study rigorously adhered to established ethical guidelines for academic research, ensuring the acquisition of informed consent and compliance with data privacy standards.
- Conflicts of interest: the author affirms that there are no conflicts of interest associated with this study.
- Acknowledgement: all contributing authors have been duly acknowledged, and all relevant author details have been appropriately documented.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MA: Data curation, Methodology, Conceptualization, Investigation, Writing – review and editing, Writing – original draft, Formal analysis. MHS: Project administration, Supervision, Validation, Writing – original draft, Resources, Visualization.

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