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Fostering Sustainable Livestock Systems in Nigeria: A Systematic Review of Climate-Smart Practices, Digital Tools, and Policy Frameworks

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ABSTRACT

Livestock production is central to Nigeria's food security, rural livelihoods, and economic development, yet it faces growing pressures from climate change, environmental degradation, disease outbreaks, and limited access to technology and markets. In response, climate-smart livestock practices, digital agricultural tools, and enabling policy frameworks have emerged as promising pathways for improving productivity, resilience, and sustainability. This study systematically reviews existing literature on sustainable livestock systems in Nigeria, with a focus on climate-smart practices, digital innovations, and policy frameworks. Following PRISMA 2020 guidelines, peer-reviewed articles, technical reports, and grey literature published between 2010 and 2025 were identified from major academic databases and institutional repositories. A total of 37 studies met the inclusion criteria and were synthesized using a narrative thematic approach. The review reveals that practices such as improved feeding strategies, breed selection, agroforestry, manure management, and integrated crop-livestock systems enhance resilience and productivity, particularly when implemented synergistically. Digital tools-including mobile advisory platforms, livestock health surveillance systems, market information services, and climate early-warning systems-demonstrate strong potential to improve decision-making and disease management, though adoption remains uneven. Policy analysis indicates fragmented institutional responsibilities, weak integration of climate-smart and digital strategies, and inconsistent implementation despite supportive national policy intentions. Overall, the evidence highlights significant progress alongside persistent gaps in adoption, coordination, infrastructure, and empirical evaluation. The study underscores the need for integrated policies, investment in rural digital infrastructure, capacity building, and evidence-based implementation to foster sustainable livestock systems in Nigeria.

Keywords: Climate-smart livestock production; Digital agricultural technologies; Low-medium-income-countries. Policy frameworks; Sustainable livestock systems.

1 INTRODUCTION

Livestock production plays a pivotal role in Nigeria's agroeconomics, contributing to gross domestic product (GDP), food and nutrition security, employment, income generation, and socio-cultural livelihoods (Uzonwanne et al., 2023). However, the sector is increasingly confronted by climate variability, land degradation, disease outbreak, greenhouse gas emissions, and limited access to technology and markets (Onyeneke et al., 2023). These constraints are of delicate concerns for smallholder and pastoral livestock systems, which represent the largest portion of livestock production in Nigeria (Ogunbiyi and Muhammad, 2023).

There is a growing interest in climate-smart agriculture (CSA) and climate-smart livestock production (CSLP), as structures capable of improving climate resilience, decreasing greenhouse gas emissions and at the same time boosting productivity (Singh et al., 2024; International Fund for Animal Welfare, 2024). Within livestock systems, climate-smart practices involve approaches like: improvement of feeding and breeding strategies, rangeland management, proper handling of manure, and integrated crop-livestock systems, growing of drought-tolerant crops, better water management, agroforestry, and improved animal husbandry to create sustainable, effective, and resilient farming schemes that guarantee livelihoods climate impacts (Singh, 2024). Digital technologies like mobile-based advisory services, GIS, remote sensing, and precision livestock tools substantially augment agricultural operations by facilitating data-driven decision-making, improving productivity, and supporting risk management. These tools

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enhance a shift from traditional, generalized farming to a more efficient, site-specific management approach (FAO, 2025).

Policy frameworks play a central role in encouraging or discouraging the adoption of these innovations (Patanakul and Pinto, 2014), by means of institutional coordination, investment, and regulation. CSA-TIMPs, an integration of climate-smart agriculture (CSA) and technologies, innovation and management practices (TIMPs) was identified to be capable of enhancing food production and climate resilience, but low awareness, weak policy support, and poor adoption in Nigeria restricts innovation and intensify farmers' climate vulnerability (Ifeanyi-Obi et al., 2022).

Despite growing research interest, evidence on climate-smart livestock practices, digital tools, and policy frameworks in Nigeria is still meagre (Ifeanyi-Obi et al., 2022). While there is increased interest and appreciation of the potential benefits, significant gaps exist in experimental data, large-scale implementation, and consistent policy integration (Abate et al., 2023). A systematic synthesis is therefore required to identify progress, gaps, and measures to adopt, towards fostering sustainable livestock systems. This review addresses this need by systematically examining existing literature on these three intersected components.

2 LITERATURE REVIEW / RELATED WORK

Throughout the reviewed literatures, there is a consistent convergence of opinion on the significance of climate-smart agriculture (CSA) and climate-smart livestock (CSL) as integrated frameworks for tackling the climate change–livestock–food security relationship, mainly in Nigeria and other low-and-middle-income countries (LMICs). Conceptual and narrative reviews (for example, Iyiola-Tunji, 2021; Aden & Niraj, 2021; Bashiru & Oseni, 2025) consistently situate CSL as a dual adaptation–mitigation approach, emphasizing practices such as improved feeding and feed efficiency, genetic improvement, animal health management, manure and waste management, and grazing or pasture optimization. Likewise, system-level methods, comprising crop–livestock integration, agroforestry, and circular economy models, are extensively identified as ways of boosting productivity, resilience, and environmental sustainability.

Regardless of this broad agreement, significant differences in contexts and systems emerge across the studies. While global and conceptual analyses (Aden & Niraj, 2021; Oke et al., 2025) incline towards promotion of technologically advanced and system-wide interventions, such as; precision livestock farming, life cycle assessment tools, and digital monitoring systems, studies focusing on LMICs and smallholder systems (Adesogan et al., 2023; Michael et al., 2025; Bashiru & Oseni, 2025) emphasise the need for context-appropriate, affordable, and socio-culturally befitting solutions. These studies argue that earlier research has overly given emphasis to the mitigation of greenhouse gas (GHG) within intensive systems, a lot at the expense of adaptation, food security, and livelihood considerations in resource-constrained settings. Subsequently, sustainable intensification strategies that incorporate productivity gains with adaptation benefits are progressively prioritized for smallholder systems.

A recurrent pattern across the literature is the low and disproportionate adoption of climate-smart practices, despite their exhibited potential. Empirical syntheses (Otitoju et al., 2023; Michael et al., 2025) ascribe this to a complex interaction of obstacles, such as; high costs, weak infrastructure, limited technical knowledge, gender and socio-economic constraints, insecure land tenure, and insufficient policy support. In addressing that, several studies (Olagunju, 2024; Oke et al., 2025) emphasize the transformative position of digital and institutional innovations, chiefly e-extension services, early warning systems, insurance schemes, and climate information services, in augmenting access to knowledge, improving decision-making, and scaling adoption. Nevertheless, while global case studies demonstrate the feasibility of such tools, their effectiveness in Nigeria and similar contexts remains thwarted by poor internet connectivity, low digital literacy, and insufficient localization of content.

Also, a vital convergence pointy is the susceptibility of specific production systems, particularly grazing-based and pastoral systems, which are consistently identified as the most exposed to climate risks such as heat stress, drought, and feed scarcity (Iyiola-Tunji, 2021; Bashiru & Oseni, 2025). Conversely, integrated and mixed systems are commonly viewed as more resilient due to their capacity to diversify risk and optimize resource use. Nevertheless, conflict-affected and ecologically fragile regions, such as Northeast Nigeria (Michael et al., 2025), present compounded vulnerabilities where climate stressors interact with socio-political instability, further limiting the effectiveness and scalability of CSA interventions.

The reviewed literature uncovers a consistent and substantial gap between the theoretical advancement of climate-smart agriculture and livestock frameworks and their empirical authentication in real-world perspectives. Across studies, there is a notable lack of meticulous quantitative evidence evaluating the effectiveness, efficiency, and environmental impact of proposed interventions, coupled with limited economic analyses that assess their cost–benefit performance and financial practicability for smallholder farmers. Closely linked is the inadequate understanding of underlying forces that influence adoption, including the roles of socio-economic, gender, behavioral, and institutional factors in shaping uptake and sustained use. Besides, much of the existing evidence are insufficiently context-specific, with

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poor attention to variations across agro-ecological zones, production systems, and conflict-affected regions. Although digital innovations such as e-extension, precision livestock technologies, and climate information systems are increasingly promoted, their scalability, usability, and impact in resource-constrained settings are still underexplored. In addition, there is limited integration of participatory approaches and indigenous knowledge systems, which constrains the relevance and inclusiveness of proposed solutions. Finally, the dominance of short-term and review-based studies underscores the absence of longitudinal and systems-oriented research capable of capturing the complex, dynamic interactions between climate change, livestock production, technological interventions, and policy environments.

By and large, the literature demonstrates strong conceptual alignment on the importance of climate-smart livestock systems but reveals a significant disconnect between theoretical frameworks and practical implementation. While a wide range of adaptation and mitigation approaches has been identified, their real-world effectiveness, scalability, and adoption remain insufficiently understood, particularly within smallholder and LMIC contexts. Addressing these gaps requires a shift toward data-driven, context-specific, and interdisciplinary research, incorporating technological innovation, socio-economic analysis, and policy frameworks to support sustainable livestock transformation.

3 METHODOLOGY

This study adopted a systematic literature review (SLR) design, guided by the PRISMA 2020 framework, to ensure transparency, reproducibility, and methodological rigor to identify, select, and synthesise relevant studies. The review concentrated on climate-smart livestock practices, digital agricultural technologies, and policy frameworks for sustainable livestock systems in low- and middle-income countries (LMICs), with specific emphasis on Nigeria and analogous sub-Saharan African settings.

A systematic approach was considered appropriate due to the heterogeneous and multidisciplinary nature of the subject, which spans animal science, climate change, digital innovation, and policy studies. The methodology was therefore designed to ensure broad coverage of appropriate literature, and the same time adhering strictly to selection criteria, so as to enhance the validity and reliability of findings.

3.1 RESEARCH DESIGN

A qualitative systematic literature review design was conducted to judiciously synthesize existing knowledge from peer-reviewed and grey literature. This design allows for the assimilation of findings from diverse study types, including empirical, conceptual, and policy-oriented research.

The choice of a qualitative synthesis approach is justified by the methodological diversity of the included studies, which disallowed meta-analysis but allowed for appraisal of themes and identification of patterns. Moreover, the design supports analytical depth over mere accumulation, ensuring that relationships, trends, and gaps across studies are expressively interpreted.

3.2 SEARCH STRATEGY

A comprehensive and structured search strategy was implemented across multiple academic databases and institutional repositories, including Scopus, Web of Science, ScienceDirect, SpringerLink, Taylor & Francis, AJOL, Google Scholar, and repositories of FAO, IFAD, and IFAW. The search covered publications from 2010 to 2025, a time frame purposely chosen to capture:

i. The development of climate-smart agriculture concepts, and
ii. The beginning and extension of digital agricultural technologies.

A combination of keywords and Boolean operators (AND, OR) was used to ensure both breadth and specificity. Core search terms included: “sustainable livestock systems,” “climate-smart livestock,” “digital agriculture,” “e-extension,” “policy frameworks,” “LMICs,” and “Nigeria”.

This multi-database and keyword-driven method was designed to minimize bias in publication and ensure far-reaching identification of relevant studies, thus reinforcing the strength of the study selection process.

3.3 INCLUSION CRITERIA

Inclusion of studies was based ON CLEARLY DEFINED CRITERIA TO ensure relevance, quality, and analytical consistency. Eligible studies were those which focused on: livestock systems within the context of climate-smart practices, digital technologies, or policy frameworks, were conducted in LMICs, particularly Nigeria and sub-Saharan Africa, provided empirical data, theoretical insights, or comprehensive reviews, were published between 2010 and 2025 and were available in English language.

The inclusion criteria were purposely designed TO ENSURE THAT only studies that are contextually relevant and methodologically sound were selected, therefore enriching the validity of the synthesis and ensuring alignment with the study objectives.

3.4 EXCLUSION CRITERIA

To further strengthen study selection and shrink bias, exclusion criteria were applied. Studies were excluded if they: focused solely on crop production without livestock integration, addressed non-food animals (for example, companion animals), lacked analytical precision or

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methodological clarity, were duplicates, non-accessible in full text, or not published in English language.

These exclusion criteria ensured that the final dataset stay focused, coherent, and directly related, thus preventing dilution of the analysis with irrelevant or studies of low quality.

3.5 DATA EXTRACTION SYNTHESIS

Following the PRISMA-guided screening process, a total of 37 studies as shown in Figure 1 were retained for final synthesis out of an initial pool of 357 identified records. The selection of these 37 studies is methodologically justified on several grounds; the multi-stage screening process (title, abstract, and full-text review) ensured that only studies meeting all inclusion criteria were retained, thereby prioritizing quality over quantity. The final number indicates thematic saturation, as no new significant themes emerged beyond this set of studies, indicating adequate coverage of the research domain. Furthermore, the sample size is in consonance with established practice in systematic reviews that deal with multidisciplinary and heterogeneous topics, where moderate sample sizes allow for deeper analytical synthesis rather than superficial accumulation.

Data extraction was conducted using a structured matrix capturing key study characteristics, including author(s), year, context, methodology, key findings, and identified gaps. A thematic narrative synthesis style was employed due to the heterogenous nature of study designs. Extracted data were organized into core themes: climate-smart livestock practices, digital tools for livestock sustainability and policy frameworks and institutional support.

This method allowed for the identification of patterns, relationships, and divergences across studies, while also facilitating the systematic identification of knowledge gaps.

3.6 QUALITY ASSESSMENT CRITERIA

The review was reported in accordance to PRISMA guidelines to ensure transparency and reproducibility. Quality assessment was performed by evaluating the relevance, credibility, and recency of each source using the Critical Appraisal Skills Programme (CASP) checklists. Particular attention was given to the validity of methodologies used in the studies, the applicability of findings to the livestock practice and policy making.

3.7 ETHICAL CONSIDERATIONS

As this review only involved secondary data collection from published and publicly accessible materials, no ethical approval was required.

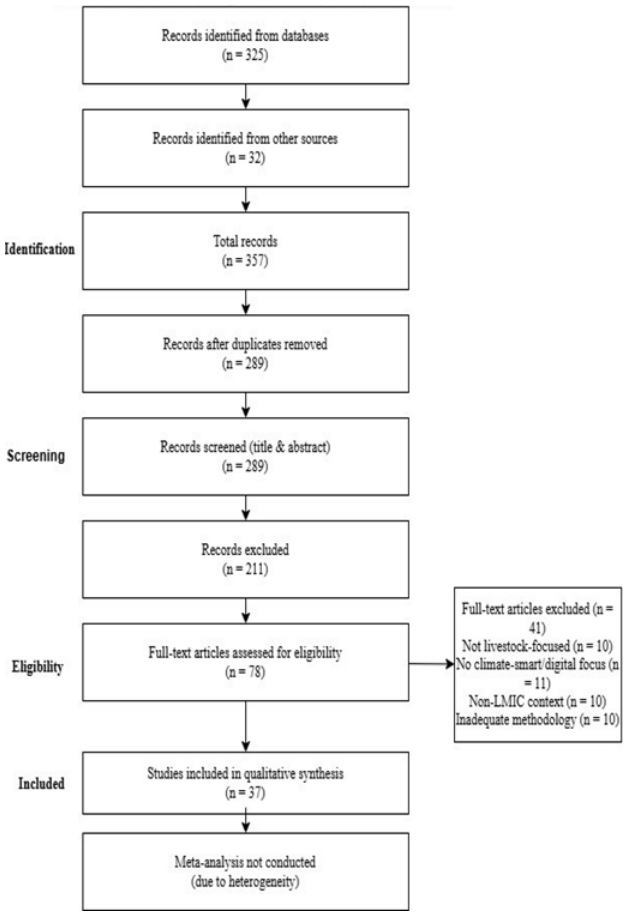


Figure 1: Flow Diagram of Study Selection Process

4 RESULTS AND DISCUSSION

In this section, a summary of some climate-smart livestock practices, digital tools supporting livestock sustainability, policy frameworks and institutional support was conducted. Furthermore, potentials for CSLP and digital innovations to transform Nigeria's livestock systems, challenges of policy incoherence, limited investments and weak coordination among stakeholders were discussed. The importance of integrating digital tools into climate-smart livestock policies and implications of the review for policy and practice were also explored.

4.1 CLIMATE-SMART LIVESTOCK PRACTICES IN NIGERIA

It is consistently established from the reviewed data, that climate-smart livestock practices (CSLPs) offer significant potential to improve productivity, resilience, and environmental sustainability within Nigerian livestock systems. Among studies, interventions such as improved feed formulation, drought-tolerant forages, climate-resilient

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breeds, manure management, and integrated crop–livestock systems are generally reported to produce combined benefits, mostly when implemented in group rather than as individual practices (Amole and Ayantunde, 2016; Iyiola-Tunji, 2021; Shahbaz et al., 2022; Hernandez et al., 2025). This convergence implies that the efficacy of CSLPs is not merely additive but system-dependent, where integrated approaches optimize resource use, nutrient cycling, and risk diversification.

However, despite strong technical evidence supporting CSLPs, a clear implementation gap persists. While experimental and pilot studies frequently report positive outcomes, real-world adoption remains limited and uneven. This discrepancy indicates that the primary limitation is not the technical authenticity of CSLPs but rather the institutional, economic, and knowledge systems required to support their uptake. High input costs, restricted access to credit, weak extension services, and low farmer awareness constantly appear as interrelated barriers (Ofoegbu, 2025; Ajibade et al., 2025; Ifeanyi-Obi et al., 2021; Terdoo and Adekola, 2014). These constraints are further aggravated by insecurity and climate variability, particularly in pastoral and semi-arid regions. Importantly, the literature exposes a contextual disagreement in effectiveness. Whereas integrated systems show higher resilience due to diversification and resource efficiency, grazing-based and pastoral systems remain disproportionately susceptible to climate stressors such as drought, heat stress, and feed scarcity (Iyiola-Tunji, 2021). This suggests that a "one-size-fits-all" approach to CSLP campaign is inefficient, and that context-specific adaptation approaches are indispensable.

From a policy perspective, the findings imply that scaling CSLPs requires a paradigm shift from technology promotion to systems strengthening. Without addressing structural barriers -chiefly access to finance, extension services, and infrastructure- adoption may be merely confined to pilot enterprises. Thus, the challenge is less about identifying effective practice, rather it is more about creating enabling atmospheres for sustained implementation (Rekwot et al., 2016; FAO, 2013; Steenwerth et al., 2014; Lipper et al., 2014).

4.2 DIGITAL TOOLS SUPPORTING LIVESTOCK SUSTAINABILITY

Digital technologies are progressively acknowledged as critical, in enabling sustainable livestock systems, especially in improving access to information, facilitating disease surveillance, and enhancing climate risk management. Throughout the literature, tools such as mobile advisory platforms, livestock health monitoring systems, market information services, and climate early-warning systems are consistently linked with improved decision-making, reduced response time to disease outbreaks, and improved adaptive capacity among farmers (World Bank, 2020; Mollel et al., 2025; Olaitan et al., 2025).

Nevertheless, the evidence reveals a notable scale-impact disengagement. Even though digital tools demonstrate strong effectiveness in controlled or pilot situations, their far-reaching influence is restricted due to systemic limitations. This advocates that the challenge is not essentially in the functioning of digital innovations, rather it lies in their scalability and integration within existing agricultural systems. In many instances, successful outcomes are narrowed to donor-driven or project-based interventions, raising concerns about sustainability beyond initial implementation phases (Mollel et al., 2025; Olaitan et al., 2024a).

A fundamental trend among studies is the role of structural imbalances in shaping digital adoption. Variations in network infrastructure, digital literacy, and affordability create lopsided access, particularly placing smallholder farmers in rural and remote regions under disadvantaged conditions (Adedeji et al., 2021; Olaitan et al., 2024a). This digital partition implies that, if technological solutions are not accompanied by inclusive infrastructure and capacity-building strategies, the existing inequalities within the livestock sector may be inadvertently reinforced.

Comparatively, countries such as Kenya and Uganda exhibit more developed integration of mobile-based livestock services, underscoring the significance of enabling ecosystems, including private-sector engagement, policy backing, and user-centred design (Odhiambo and Wangari, 2020; Abubakar et al., 2024). Conversely, Nigeria's slower uptake indicates gaps in infrastructure, institutional coordination, and localized content development (Adedeji et al., 2021; Olaitan et al., 2024a).

By implication, digital transformation in livestock systems cannot be achieved by deploying technology alone. Rather, it requires a systems-oriented approach that combines infrastructure development, digital literacy, institutional support, and policy alignment. Except by harmonising these investments, digital tools are not likely to achieve their transformative abilities at substantial scale (Izuogu et al., 2023; FAO, 2025).

4.3 POLICYFRAMEWORK AND INSTITUTIONAL SUPPORT

The analysis of policy frameworks shows a constant gap between policy goals and implementation in Nigeria's livestock sector. Although national strategies such as the National Agricultural Technology and Innovation Policy (NATIP) and the Nigeria Livestock Master Plan (N-LMP) clearly identify the significance of climate-smart and digital innovations, their pragmatic impact remains limited (FMARD, 2022; ILRI, 2019). This discrepancy implies that

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policy effectiveness is less hindered by design deficiencies, but more by institutional and governance challenges.

A recurrent issue throughout the literature is institutional fragmentation, which can be attributed to weak coordination among government agencies, overlapping mandates, and inconsistent policy execution across federal, state, and local levels (Patanakul and Pinto, 2014). This disintegration weakens coherence and decreases the efficiency of resource allocation, therefore limiting the scalability of climate-smart and digital interventions.

Additionally, the lack of sustained financing mechanisms and weak monitoring and evaluation systems constitute further challenge to policy outcomes. Although initiatives such as the Livestock Productivity and Resilience Support Project (L-PRES) demonstrate potential for integrating climate adaptation and digital tools, their long-term impact depends on institutional consistency and funding stability, which is uncertain (Global Center on Adaptation, 2023).

Another important gap lies in the lack of clear regulatory structures for digital agriculture, particularly in areas such as data governance, digital public goods, and private-sector participation. This restrains innovation and reduces investor confidence, thereby slowing down the pace of development of scalable digital solutions.

Relatively, evidence from other contexts suggests that efficient policy implementation is largely associated with multi-stakeholder coordination, decentralized governance, and strong institutional capacity. The Nigerian case, therefore, highlights the need for a shift from policy design to policy operationalization, supported by clear accountability procedures and stakeholder involvement.

On the whole, the findings reveal that achieving sustainable livestock transformation requires not only well-formulated policies but also institutional alignment, effective coordination, and implementation ability (Ifeanyi-Obi et al., 2022).

4.4 PREVIOUS STUDIES RECOMMENDATIONS

Recommendations from reviewed literature reveal strong convergence around the necessity of integrated, systems-based approaches to sustainable livestock development. A fundamental idea is the importance of amalgamating climate-smart livestock schemes with national agricultural and climate policies, implying that policy consistency is a requirement for scaling innovation and achieving long-term sustainability (Iyiola-Tunji, 2021; Aden and Niraj, 2021; Bashiru and Oseni, 2025).

However, a closer analysis shows that many of these recommendations, while theoretically sound, remain inadequately operationalized. For example, campaign for farmer awareness, capacity building, and participatory approaches are widespread, yet evidence shows that these interventions are often put into operation in a disjointed or interim manner (Michael et al., 2025; Adesogan et al., 2023). This indicates a disengagement between recommended strategies and their practical execution, particularly in resource-constrained settings.

Another key pattern is the emphasis on human and institutional capacity development. Findings consistently emphasise the need for intensifying extension systems, boosting digital literacy, and incorporating indigenous knowledge into climate adaptation strategies (Iyiola-Tunji, 2021; Aden and Niraj, 2021; Michael et al., 2025). This signifies a broader recognition that technological interventions alone are insufficient, in the absence of corresponding investments in people and institutions.

With respect to digital innovation, several studies emphasise the significance of improving rural connectivity, developing localized digital content, and promoting data-driven decision-making tools (Olagunju, 2024; Mollel et al., 2025). However, the persistence of infrastructure and affordability challenges implies that these recommendations require substantial financial and policy commitment to be maximally realized.

Additionally, the literature stresses the role of multi-stakeholder partnerships, including public–private collaborations, in tackling systemic impediments to adoption (Otitoju et al., 2023; Mollel et al., 2025). Despite the endorsement of this approach, its efficiency relies heavily on strong coordination systems and clearly stated institutional responsibilities, which remain limited in practice.

Taken together, these discoveries insinuate that future efforts should move towards developing context-specific, implementable, and evidence-based strategies, instead of merely reiterating broad recommendations. Beyond technical innovation, achieving the afore-mentioned require institutional reform, sustained investment, and participatory governance structures that ensure inclusivity and long-term impact.

4.5 IMPLICATIONS FOR POLICY AND PRACTICE

In other to translate existing evidence into pragmatic outcomes, policy recommendations are prioritised on short-, medium-, and long-term bases, according to their feasibility and systemic impact.

4.5.1 SHORT-TERM PRIORITIES (0–2 YEARS): ENABLING ADOPTION AND ACCESS

To begin with, policymakers should reinforce last-mile delivery systems by reviving extension services through digital–physical integration (e-extension platforms combined with field agents). This includes targeted training in climate-

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smart livestock practices and use of digital tools for both farmers and extension officers.

Moreover, government and development allies should make digital infrastructure more accessible and affordable, particularly by subsidizing mobile data services and upgrading network coverage in major livestock-producing regions. In the absence of instant improvements in connectivity, digital innovations will remain an illusion.

Furthermore, establishment of pilot-to-scale transition frameworks is very necessary, ensuring that successful donor-driven or pilot interventions are thoroughly evaluated and scaled through public programs, instead of discontinuing them after project cycles.

4.5.2 MEDIUM-TERM PRIORITIES (3–5 YEARS): SYSTEMS STRENGTHENING AND INTEGRATION

Policymakers should develop and operationalize a well-coordinated national framework, that combines climate-smart livestock strategies with digital agriculture policies, thus, reducing institutional fragmentation. Achieving this requires clearly defined roles across federal, state, and local agencies.

Similarly, governments should establish sustainable financing mechanisms, including blended finance models and targeted credit schemes, as theses will support farmer adoption of climate-smart and digital innovations.

In the same vein, investment in localized digital content and platforms is germane to ensure relevance across different agro-ecological zones and production systems.

4.5.3 LONG-TERM PRIORITIES (5+ YEARS): INSTITUTIONAL TRANSFORMATION AND SUSTAINABILITY

On a long-term basis, achieving sustainable livestock transformation will require institutional restructuring and regulatory advancement, mainly in areas such as data governance, digital agriculture standards, and private-sector participation.

Also, institutionalizing a robust monitoring and evaluation systems is very essential. As that will enable continuous learning, impact assessment, and adaptive policymaking.

Conclusively, policies should promote multi-stakeholder governance prototypes, which will integrate public institutions, private actors, researchers, and livestock producers to ensure inclusive and sustained system transformation.

4.6 LIMITATIONS OF REVIEW

This review comprises several limitations that should be considered in interpreting the findings.

Foremost, the study relies solely on secondary data sources, which implies dependence on the methodological quality, scope, and assumptions of the original studies. Differences in research design, sample size, and analytical approaches across the included literature may limit the ability to compare and as well bring about discrepancies in the robustness of evidence, thereby affecting the strength of the derived conclusions.

Furthermore, the absence of quantitative meta-analysis, due to heterogeneous nature of study designs and outcome measures, hinders the ability to generate statistically aggregated effect sizes. Consequently, the findings are primarily interpretive and thematic, which, is although valuable for identifying patterns, may place limits on precision in estimating the magnitude of impacts of climate-smart and digital interventions.

Besides, a substantial proportion of the reviewed studies are based on pilot projects and donor-funded interventions, which is capable of overrepresenting positive outcomes and underreporting implementation issues. This presents a potential publication and project bias, connoting that the effectiveness of climate-smart practices and digital tools may be overestimated relative to real-world conditions.

Likewise, the review is constrained by contextual and geographical inconsistency, with limited disaggregation across agro-ecological zones, production systems, and socio-economic groups within Nigeria. This reduces the ability to generalize findings and may conceal context-specific dynamics that determine adoption and impact.

In addition, although the review highlights policy frameworks, policy design is more emphasized by much of the underlying literature, rather than implementation outcomes, thus limiting the ability to assess actual effectiveness at the farm level. This creates a policy–practice inference gap, where conclusions about impact may not fully represent current realities.

To conclude, the rapidly evolving nature of digital agricultural technologies and climate risks implies that some findings may soon become outdated, especially with respect to emerging tools, data systems, and governance models.

All together, these limitations imply that the findings should be interpreted with contextual caution, and they underscore the need for longitudinal, mixed-method, and impact-inclined research that integrates technical, socio-economic, and policy dimensions of sustainable livestock systems.

4.7 CONTRIBUTION TO KNOWLEDGE

This study contributes to knowledge by incorporating climate-smart livestock practices, digital technologies, and policy frameworks into a combined systems perspective, addressing the disjointed approach of discussing them in existing literature. It demonstrates that sustainable livestock

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transformation in Nigeria does not depend on isolated innovations, rather on the efficient integration of technological, ecological, and institutional systems.

The study further pinpoints a critical implementation gap, revealing that albeit proven benefits, adoption and impact stay limited due to structural and institutional constraints, rather than lack of innovation. It also introduces the concept of a scale-impact disconnection, underscoring that digital livestock solutions thrive well in pilot contexts but faced with significant barriers to widespread and sustained use.

Furthermore, our findings make available evidence of policy fragmentation and weak operationalization, pointing to the fact that, policy effectiveness is constrained more by coordination and implementation related issues, compared to design limitations.

Methodologically, the study offers a PRISMA-guided, context-specific synthesis (2010–2025) and highlights key research gaps, particularly in longitudinal evidence, cost-benefit analysis, and underlying forces influencing adoption.

Overall, the study advances a systems-based understanding of livestock sustainability, emphasizing integration, scalability, and institutional coherence as vital to achieving meaningful and lasting impact.

5 CONCLUSION

This review establishes that climate-smart livestock practices, digital innovations, and enabling policy frameworks collectively offer viable pathways for reinforcing sustainable livestock systems in Nigeria. Evidence shows that integrated approaches-combining improved nutrition, resilient breeds, resource-efficient management, and digital decision-support tools- are capable of boosting productivity, climate resilience, and environmental performance, particularly for smallholder and pastoral systems. However, progress remains uneven and largely restricted to pilot initiatives, with adoption hindered by weak infrastructure, limited capacity, fragmented institutional arrangements, and inconsistent policy implementation.

The findings highlight a persistent gap between policy goals and execution. Despite increasing acknowledgement by national strategies of sustainability, climate resilience, and digital transformation, operationalization within the livestock sector remains restricted. Addressing this disconnect requires coordinated, evidence-based policies, sustained investment in rural digital infrastructure, intensified extension systems, and inclusive, farmer-centred implementation models.

By and large, fostering sustainable livestock systems in Nigeria will rely not only on technological innovation, but also on coherent governance, institutional alignment, and long-term commitment to capacity building and participatory approaches. Future research should prioritize quantitative, longitudinal, and context-specific studies to better inform policy design, assess cost-benefit performance, and support scalable, locally relevant solutions.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest related to this work.

AUTHORS' CONTRIBUTIONS

Yakub Adenuga was involved in the literature search and review. Yakub Adenuga and Mariam Salako jointly contributed to the conceptualization and design of this review. Kayode Adenuga critically revised the manuscript for intellectual content and provided final approval for submission.

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