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Evaluation of Sustainability of Cattle Farming Through Social, Economic, Ecological, and Technological Approaches In Sinjai Regency, South Sulawesi Province, Indonesia

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Abstract

Smallholder cattle farming systems in developing countries are increasingly expected to balance economic viability, ecological integrity, technological adaptability, and social inclusiveness. However, sustainability assessments often remain fragmented, overlooking cross-dimensional interactions and masking potential systemic fragility. This study evaluates the sustainability of beef cattle farming in Sinjai Regency, South Sulawesi, Indonesia, by operationalizing the Social–Ecological–Technological Systems (SETS) framework and integrating a composite sustainability index with SWOT-based strategic diagnostics. Primary data were collected from 37 cattle farmers and analyzed across four dimensions: social, economic, ecological, and technological. The results indicate an overall sustainability index score of 2.77, placing the system in the moderate category. The technological dimension (2.84) slightly outperforms ecological and economic dimensions (2.78 each), while the social dimension records the lowest score (2.65). Disaggregated ecosystem service mapping reveals strong performance in supporting functions driven by farmer interest, land and water availability, and baseline production practices, yet weaker outcomes in provisioning and socially mediated adjustment functions. In particular, limited farmer cooperation, low income generation, and insufficient labor absorption constrain the effective conversion of ecological and technological resources into economic resilience. These findings suggest that moderate sustainability performance reflects a stable but suboptimal equilibrium rather than full systemic resilience. The system exhibits structural capacity but faces a transformation bottleneck due to insufficient cross-dimensional integration. By bridging multidimensional measurement with strategic positioning, this study contributes to refining sustainability assessment in smallholder livestock contexts. It highlights the need for coordinated strengthening of social capital, institutional governance, and technological upgrading to achieve transformative sustainability transitions.

1. Introduction

Livestock production is experiencing a significant transformation due to increasing global pressures related to food security, climate change, environmental degradation, and rural inequality (Chandra et al., 2025; Hasan et al., 2020). In particular, beef cattle systems in developing countries are increasingly expected to achieve economic viability, ecological integrity, technological adaptability, and social inclusiveness simultaneously (Castonguay et al., 2023). However, the current development paradigm continues to prioritize productivity growth as the primary indicator of success, often neglecting the systemic vulnerabilities inherent in smallholder production structures. Consequently, livestock systems may appear stable in terms of output while remaining structurally fragile concerning adaptive resilience and long-term sustainability (Bilotto et al., 2024; Hasan et al., 2019).

In Indonesia, cattle farming is predominantly smallholder-based and integrated within mixed crop–livestock systems characterized by limited capital, reliance on family labor, informal market linkages, and fluctuating feed resources (Hilmiati et al., 2024). While these systems exhibit social cohesion and livelihood flexibility, they often operate within low-technology, low-productivity equilibria(Martínez-Ramón et al., 2026). Environmental pressures, including land-use changes, soil fertility decline, and water

competition, further exacerbate systemic constraints (Hasan et al., 2019; Khaerani et al., 2024). These conditions reveal a structural contradiction: resource endowment and social participation coexist with technological stagnation, moderate economic returns, and vulnerability to market volatility (Thom et al., 2024). Without systemic intervention, such equilibria risk reinforcing path dependency rather than facilitating transformative sustainability transitions.

Despite the growing body of research on livestock sustainability, existing studies remain conceptually fragmented and analytically incomplete (Friedrich et al., 2022). Many studies isolate environmental efficiency, economic profitability, or social welfare indicators, implicitly assuming additive rather than co-evolutionary relationships among sustainability dimensions. Even when multidimensional frameworks are employed, technological capacity is often treated as an auxiliary factor rather than a dynamic subsystem that actively reshapes ecological efficiency and socio-economic performance (Selin & Selin, 2022). Consequently, current sustainability assessments fail to capture how technological inertia, institutional arrangements, and ecological resource dynamics interact to shape long-term resilience in smallholder livestock systems (Bilotto et al., 2024).

Although the Social–Ecological Systems (SES) framework has gained prominence in sustainability science, its extension into an explicitly operationalized Social–Ecological–Technological Systems (SETS) framework within livestock contexts remains theoretically underdeveloped and empirically scarce (Figueroa et al., 2025). In smallholder cattle systems, technology is not merely an enabling input; it mediates feed efficiency, disease management, waste reduction, production scaling, and adaptive response to climate variability (Daum et al., 2021; Hasan et al., 2024; Utamy et al., 2021).

However, few empirical studies have quantified how technological practices co-evolve with ecological resource availability and social capital at the regional scale in developing-country livestock systems (Pérez-Lombardini et al., 2024). This theoretical under-specification limits the explanatory power of sustainability science in rural production landscapes. A further methodological limitation constrains policy translation. Composite sustainability indices provide standardized multidimensional measurement but frequently lack strategic interpretability. Conversely, SWOT analyses offer strategic diagnosis without quantitative grounding. The absence of integrative designs that bridge systematic sustainability scoring with strategic positioning creates a disconnect between measurement and actionable transformation pathways (Pereira et al., 2021). As a result, policy interventions often target symptoms such as feed shortages or low productivity without addressing systemic coordination failures among interdependent subsystems (Schneider et al., 2025).

In South Sulawesi Province, notable conceptual and methodological gaps exist, particularly in the context of beef cattle farming, which is a vital rural livelihood strategy. Sinjai Regency, within this region, benefits from favorable conditions such as land and water availability, crop–livestock integration, and robust community participation (Chandra et al., 2025). However, challenges such as moderate productivity, limited technological advancement, seasonal feed instability, and market vulnerability persist (Paudyal, 2024). This paradox prompts a critical research inquiry: do moderate sustainability

outcomes indicate structural stability or underlying systemic fragility? Without a comprehensive, system-level evaluation, regional livestock policies may inadvertently support incremental changes rather than fostering adaptive transformation.

This study, situated at the confluence of sustainability science, systems theory, and rural development economics, contributes to the field in three significant ways. Firstly, it applies the Social–Ecological–Technological Systems (SETS) framework to a smallholder cattle farming context, extending its empirical application from urban and infrastructural domains to agricultural production systems. Secondly, it addresses the measurement–strategy gap by integrating composite sustainability indexing with SWOT-based strategic diagnostics, thereby enhancing both analytical rigor and policy relevance. Thirdly, it provides region-specific evidence from an underexplored livestock production landscape in eastern Indonesia, thereby enriching the diversity of empirical cases in global sustainability discourse.

By reconceptualizing cattle farming as a complex adaptive system shaped by interdependent social, ecological, technological, and economic dynamics, this study moves beyond conventional performance-based assessments toward a systemic resilience perspective (Broom, 2023). It explicitly operationalizes the Social–Ecological–Technological Systems (SETS) framework within a smallholder livestock context, an application that remains theoretically underdeveloped and empirically limited in current sustainability literature. In doing so, the research bridges a critical measurement strategy divide by integrating multidimensional sustainability indexing with SWOT-based strategic diagnostics, thereby enhancing both analytical precision and policy applicability (Muis et al., 2025).

More importantly, this study advances sustainability transition scholarship by empirically interrogating whether smallholder cattle systems represent structurally locked equilibria or adaptive systems with latent transformative capacity. By providing region-specific evidence from a resource-constrained rural production landscape, it offers methodological clarity and strategic depth that have been largely absent in prior livestock sustainability assessments (Kazanski et al., 2025). The findings not only inform evidence-based regional livestock policy but also contribute to refining multidimensional sustainability evaluation frameworks applicable to smallholder agricultural systems in developing economies.

2. Methodology

2.1 Technique Analysis

This study utilized several complementary analytical approaches, namely the Socio-Ecological-Technological Systems (SETS) framework, SWOT analysis, and the development of a sustainability index. Figure 1 displays the research framework with the three analyses. The SETS framework served as a heuristic lens that helped position and connect diverse perspectives in understanding complex systems, particularly social, ecological, and technological domains. The primary objective of the SETS approach was to explore how socio-technological, socio-ecological, and ecological-technological

interactions shaped emergent patterns and systemic transformations across multiple spatial and temporal scales (Branny et al., 2022).

SWOT analysis was adopted as a strategic assessment tool that systematically evaluated internal capacities alongside external environmental conditions, thereby supporting informed managerial and policy decision-making (Hills & Westbrook, 1997). By clearly distinguishing organizational strengths and weaknesses from external opportunities and threats, this framework enabled structured reflection on strategic positioning. This approach assisted decision-makers in aligning institutional resources with evolving external dynamics and uncertainties. When integrated with quantitative indicators or embedded within an index-based framework, SWOT analysis further enhanced analytical rigor in policy formulation and contributed to more coherent long-term sustainability planning (Hills & Westbrook, 1997).

The sustainability index developed in this study was constructed by aggregating the average scores of key indicators across four core dimensions: social, economic, ecological, and technological. Each dimension was first operationalized through selected measurable indicators, and their scores were standardized to ensure comparability across domains. The composite index reflected a balanced integration of these four pillars, representing overall sustainability performance from a SETS perspective. By synthesizing multidimensional indicators into a single composite measure, the index provided a systematic basis for evaluation, inter-unit comparison, and strategic policy prioritization.

Source: Author Compilation (2026)

2.2 Source of Data

The data used in this study were primary data collected through a survey of 37 cattle breeders in Sinjai Regency, South Sulawesi Province, Indonesia. Sinjai Regency was selected as the research location because it is one of the leading cattle-producing areas in the region, characterized by significant livestock activity and strong economic relevance. Furthermore, the area provided a suitable context for examining the research variables due to its agricultural characteristics, accessibility, and the central role of cattle farming in supporting the local economy. The questionnaire in this study based on the four aspects, namely social, economy, ecology, and technology with the detail explanation of indicator in Fig. 2.

Source: Author Compilation (2026)

3. Result and Discussion

Before engaging in ecosystem service mapping and strategic diagnostics, it is analytically essential to examine the internal structure of sustainability performance across four interdependent dimensions: social, economic, ecological, and technological. Aggregate sustainability scores often create a misleading impression of systemic coherence, concealing latent asymmetries within subsystem interactions. In complex adaptive systems such as smallholder cattle farming, sustainability is not

merely the arithmetic sum of multidimensional adequacy; rather, it emerges from the dynamic alignment, feedback integration, and co-evolutionary coupling among subsystems (Malik, 2022).

In this context, moderate overall performance may not indicate equilibrium or resilience, but rather a state of constrained transformation. Smallholder livestock systems often persist within what resilience theory describes as a “stable but suboptimal basin,” where foundational assets coexist with limited upgrading capacity. Social capital may remain robust, natural resources may be relatively sufficient, and basic technological practices may be partially implemented. Yet, without systemic coordination, these assets fail to generate cumulative adaptive gains. Such configurations reflect structural persistence rather than transformative sustainability (Llyod & Lewis, 2024; Nabilah & Fawzi, 2025).

The multidimensional evaluation conducted in this study disaggregates sustainability into its operational components, capturing farmer-level motivations, institutional practices, resource management strategies, and technological adoption patterns. Rather than treating these dimensions as additive pillars, the analysis examines their relational coherence. Do technological practices enhance ecological efficiency? Does social participation translate into economic upgrading? Or do subsystem misalignments create friction that constrains systemic evolution?

Preliminary patterns suggest that sustainability performance is unevenly distributed. Strong supporting foundations, such as farmer interest, land and water availability, and baseline production management, indicate structural capacity. However, weaker provisioning outcomes and socially mediated adaptive functions reveal a transformation bottleneck. In other words, the system possesses assets but struggles with conversion efficiency (Fanning et al. 2020). This distinction is critical: resilience depends not only on resource availability but also on the capacity to mobilize and integrate those resources through institutional coordination and technological embedding.

By presenting indicator-level performance across all dimensions, the following figure provides more than descriptive measurement; it serves as a diagnostic lens into systemic alignment. The visualization enables the identification of leverage points where subsystem reinforcement is required and where latent fragility may accumulate under external shocks such as market volatility or climatic stress. This disaggregated baseline assessment thus constitutes a necessary analytical step. It reframes sustainability not as a static performance category, but as a dynamic systems property shaped by cross-dimensional feedbacks. Only after identifying structural asymmetries within this internal configuration can ecosystem service mapping and strategic positioning be meaningfully interpreted.

Figure 3 presents the sustainability scores of 37 cattle farmers across social, economic, ecological, and technological dimensions. In the social dimension, farmer interest scored highest (3.73), supported by strong family participation (3.57) and community participation (3.08), indicating solid social support for beef cattle farming activities. However, cooperation among farmers (2.08), business success (1.95), and employment (1.51) remained low, indicating that strong motivation has not translated into substantial economic results. From an economic perspective, feed quality received the highest score (3.97), followed by market availability (3.30), reflecting adequate production standards and market access.

However, farmer income (2.03) and feed prices (1.84) were relatively low, indicating that rising input costs continue to limit profitability despite acceptable product quality and market access. Ecologically, efficient water availability (3.86) and land availability (3.32) were rated positively, along with waste reduction efforts (3.16). However, feed availability (2.32) and farmer involvement in environmental management (2.05) indicate that ecological sustainability practices have not been fully optimized. The use of artificial insemination (2.81) indicates partial adoption of reproductive technologies, although implementation remains limited. Within the technology dimension, land management and grass cultivation (3.76), production management (3.46), and seed selection (3.38) demonstrated relatively strong performance.

In contrast, husbandry management (1.92) and pen conditions (1.95) scored the lowest, highlighting weaknesses in core technical practices. Technology modification (2.57) was at a moderate level, indicating that innovation adoption is emerging but still under development. Overall, although motivation, resource availability, and certain production practices appear relatively strong, improvements in technical management, cost efficiency, collaboration, and innovation adoption are critical to enhancing the long-term sustainability and competitiveness of beef cattle farming (Wei et al. 2022; Abdullah et al. 2023).

Table 1 illustrates the mapping of sustainability indicators for beef cattle businesses based on the Social–Ecological–Technological Systems (SETS) framework, linked to the ecosystem service categories of provisioning, adjustment (regulating), supporting, and socio-cultural. This approach emphasizes that sustainability does not exist in a single dimension but is formed from the interaction between social, ecological, and technological systems. In the provisioning function, the social system is represented by the success of the beef cattle business, the ecological system by sustainability improvements, and the technological system by technological modifications used at the business level. This indicates that economic output and production sustainability are strongly influenced by the ability of farmers to integrate technological innovation with sustainable natural resource management, support some previous literatures (Abda-Seguara et al. 2024; Sembiring et al. 2025). In the adjustment function, the social system encompasses cooperation between farmers and employment, while the ecological system emphasizes waste reduction, and the technological system encompasses maintenance management, production management, and land management and grass cultivation.

This dimension illustrates the adaptive capacity of beef cattle businesses in responding to internal and external pressures through social collaboration, environmentally friendly practices, and technical managerial strengthening. In the supporting function, the social system is demonstrated through the interests of farmers, the ecological system through the availability of land, water, and feed, and the technological system through seed selection. This aspect reflects the basic foundations that support business sustainability, including actor motivation, natural resource availability, and the quality of production inputs. Meanwhile, in The socio-cultural category, the social system encompasses family and community participation, while the ecological system reflects increased farmer involvement in environmental management. There are no specific indicators for the technological system in this category. This dimension emphasizes that sustainability is also significantly influenced by social support

and collective awareness of environmental management practices. Overall, this mapping demonstrates that the sustainability of the beef cattle business is the result of a complex interaction between social, ecological, and technological factors. The SETS approach helps identify points of strengthening needed to ensure a more balanced integration of these three systems to promote sustainable livestock development (Niloofar et al. 2023).

Table 1
SETS Framework Analysis

Ecosystem Service	**Social System**	**Ecology System**	**Technology System**
Provision	Success of beef cattle business	Sustainability Improvement	Modification of Technology Used in the Farm
Adjustment	Farmer cooperation Absorption of labor	Waste Reduction	Maintenance Management Production Management Land Management and Grass Planting
Supporting	Breeder Interest	Land Availability Water Availability Forage Availability	Seeds Selection
Social-Culture	Family Participation Community Participation	Increasing Farmer Engagement	N/A
Source: Author Compilation (2026)			

Table 2 shows variations in the level of achievement for each ecosystem service function. In the provisioning function, the social system scored 1.95, the ecological system 2.81, and the technological system 2.26. This indicates that although ecological support for sustainability is relatively better, social and technological achievements in generating economic output are still suboptimal. In other words, the resource foundation is available, but has not been fully converted into strong business success. In the adjustment function, the social system scored 1.80, while the ecological and technological systems scored 3.16 and 3.05, respectively.

These findings indicate that environmental management and technical practices are relatively more adaptive than the social dimension, particularly in terms of collaboration and labor absorption. This imbalance indicates that technical adaptive capacity has developed, but strengthening social capital is still needed. In the supporting function, all three systems showed relatively high achievements, namely 3.73 (social), 3.17 (ecological), and 3.38 (technological). This reflects that the interests of livestock farmers, the availability of natural resources, and the quality of technical inputs provide a strong foundation for supporting the sustainability of beef cattle farming. Meanwhile, in the socio-cultural

dimension, the social system scored 3.23, while the ecological system scored 2.05, and there were no specific indicators for the technological system. These findings indicate that social support is relatively good, but the integration of ecological awareness into social practices still needs to be strengthened. Overall, the SETS approach confirms that the sustainability of beef cattle farming demonstrates a strong supporting foundation, but still faces challenges in the provisioning function and the social dimension in the adaptation aspect. Strengthening the integration between social, ecological, and technological systems is key to achieving a more balanced and sustainable sustainability.

Table 2
The Score of SETS Framework

Ecosystem Service	Social System	Ecology System	Technology System
Provision	1.95	2.81	2.26
Adjustment	1.80	3.16	3.05
Supporting	3.73	3.17	3.38
Social-Culture	3.23	2.05	N/A
Source: Author Compilation (2026)			

The SWOT analysis shows that the beef cattle business has several internal factors that support sustainability, but also faces various structural and external challenges. In terms of strengths, the livestock business is supported by family and community participation in production activities and feed provision. High levels of farmer interest also provide important social capital in maintaining sustainable business practices. Furthermore, the availability of natural resources such as land and water is relatively adequate, and most basic technological practices have been implemented.

This combination of factors indicates that the social foundation and physical resources of the business are quite strong. However, there are several weaknesses that require attention. Labor absorption and the business success rate are still low, indicating that the economic impact is not optimal. Feed availability and efforts to improve sustainability are also still limited. Furthermore, although some technologies have been implemented, more specific and modern technical aspects are still underdeveloped. Externally, there are several opportunities that can be exploited.

Good product quality and market availability open up space for broader business development. Social capital in the form of family and community participation can be strengthened to enhance cooperation among farmers. Furthermore, support from the feed industry and access to financing have the potential to increase revenue and strengthen overall business success. On the other hand, there are also threats that could hamper business sustainability. Low feed prices and low farmer incomes can undermine business economic stability.

Risks in livestock and business management can also disrupt production sustainability. Furthermore, low technological innovation and collaboration among stakeholders increase vulnerability to market

changes and environmental pressures. Overall, the SWOT analysis shows that although the beef cattle business has a strong social foundation and resources, strengthening managerial aspects, technological innovation, and collaboration among stakeholders are strategic priorities to minimize weaknesses and anticipate external threats.

Table 3
SWOT Analysis

Strength	**Weakness**
1. Theres is a family and community participation in corn farming for animal feed. 2. Farmers' interest can support the sustainability of this agricultural practice. 3. Availability of adequate land and water. 4. Most basic technological practices have been conducted	1. Low labor absorption and success of beef cattle businesses. 2. Limited availability of animal feed and improvements in the sustainability of livestock businesses. 3. Relatively advanced and specific technological aspects remain weak.
Opportunity	Threats
1. Product quality and market availability can open up opportunities for business development. 2. Social capital in the form of family and community participation can be leveraged to strengthen cooperation between farmers. 3. Strengthening the food/feed industry and providing financial support has the potential to increase income and business success.	1. Low prices for animal feed products and farmer incomes have the potential to reduce business sustainability. 2. Issues with animal feed and husbandry management risk compromising the sustainability of beef cattle farming. 3. Low technological innovation and collaboration among stakeholders can increase vulnerability to market and environmental changes.
Source: Author Compilation (2026)	

Figure 4 displays the results of the sustainability index through a spider web diagram, indicating that the technology dimension achieved the highest score of 2.84, followed by the economic and ecological dimensions, each with a score of 2.78. Meanwhile, the social dimension scored 2.65, the lowest compared to the other dimensions. These scores indicate that technology is the most developed dimension in supporting the sustainability of the beef cattle business, particularly in terms of production management and the implementation of technical practices.

The economic and ecological dimensions are at a fairly balanced level, indicating that market support, input quality, and natural resource management are operating at a moderate level. However, the lower social dimension indicates that collaboration, the economic impact on labor, and institutional strengthening still require further attention. Overall, the Sustainability Index score of 2.77 indicates that the level of sustainability of the beef cattle business is in the moderate category. This indicates that although the foundations of the social, economic, ecological, and technological systems have been

established, integrated strengthening across all dimensions is still needed to achieve optimal and balanced sustainability.

Source: Author Compilation (2026)

4. Discussion

This study aimed to investigate whether moderate sustainability performance in smallholder cattle systems signifies structural stability or underlying systemic fragility. By employing the Social–Ecological–Technological Systems (SETS) framework and integrating composite index analysis with SWOT diagnostics, the findings reveal a nuanced pattern: while foundational supporting functions remain relatively robust, provisioning and socially mediated adaptive functions exhibit structural weaknesses. These imbalances suggest that the system operates within a semi-stable equilibrium rather than a fully resilient configuration.

The sustainability index score (2.77) categorizes the cattle farming system as moderate, with technological performance (2.84) slightly surpassing ecological and economic dimensions (2.78 each), while the social dimension lags (2.65). At first glance, this configuration may appear balanced. However, when disaggregated through the SETS ecosystem service mapping, a more complex dynamic emerges. The supporting function demonstrates relatively high scores across all three systems: social (3.73), ecological (3.17), and technological (3.38), indicating strong farmer interest, resource availability, and baseline production inputs. Such conditions represent what resilience theory would describe as structural capacity: the presence of foundational assets that enable system persistence (Cradock-Henry, 2021; Darnhofer, 2021).

However, this structural capacity has not translated into proportional improvements in provisioning performance. The social score under the provisioning function (1.95) remains low, suggesting that business success and income generation are not aligned with resource endowment. Ecological and technological scores under provisioning (2.81 and 2.26, respectively) also reflect partial conversion efficiency. This pattern indicates a transformation bottleneck: although natural resources and farmer motivation are present, institutional coordination, collaboration, and advanced managerial practices limit the realization of value. Similar dynamics have been observed in smallholder livestock systems, where technological adoption does not automatically lead to economic upgrading without parallel institutional strengthening (Korir et al., 2023; Lema et al., 2021).

The adjustment (regulating) function further reinforces this interpretation. While the ecological (3.16) and technological (3.05) dimensions exhibit relatively strong adaptive practices, such as waste reduction and production management, the social dimension remains weak (1.80). This imbalance implies that adaptation is occurring primarily at the technical and environmental levels, rather than through strengthened social capital or cooperative governance. From a systems perspective, such asymmetry reduces collective adaptive capacity, potentially increasing vulnerability to external shocks such as feed price volatility or climatic variability. In line with findings from Pérez-Lombardini et al. (2024), adaptive

resilience in smallholder systems depends not only on environmental practices but also on social coordination and institutional cohesion.

The SWOT analysis corroborates these structural tensions. Strengths are concentrated in social participation and resource availability, yet weaknesses cluster around labor absorption, income stability, and advanced technological refinement. Importantly, external threats, including low feed prices, limited innovation diffusion, and market volatility, interact with these internal weaknesses. This interaction reflects what sustainability transition literature describes as path dependency: systems that maintain basic operational continuity but lack transformative upgrading mechanisms (Conti et al., 2021). In such contexts, moderate index scores may mask systemic fragility.

Technology is the most robust dimension of sustainability; however, its distribution within it is uneven. While land management and grass cultivation exhibit relatively high scores, core husbandry management and pen conditions remain deficient. This pattern suggests incremental technological diffusion rather than comprehensive modernization, as Selin and Selin (2022) contend within the human–technical–environmental systems framework. Within this framework, technology functions as a mediating subsystem that enhances ecological efficiency and socio-economic outcomes only when it is institutionally and behaviorally integrated. In the case of Sinjai, technological practices appear partially embedded but not fully institutionalized.

The relatively lower social sustainability score underscores a critical leverage point. Weak farmer cooperation and limited economic impact indicate that the cattle system operates more as a supplementary livelihood strategy than as an integrated rural enterprise. Strengthening cooperative networks, enhancing collective marketing arrangements, and improving labor absorption mechanisms could facilitate the conversion of ecological and technological capital into economic resilience. Such interventions align with governance-based transformation strategies identified in food system transition studies (Manevska-Tasevska et al., 2021).

Overall, the findings suggest that Sinjai's smallholder cattle system has a strong foundation but encounters inefficiencies in provisioning and in socially mediated adaptation. This configuration reflects structural persistence without full systemic integration. Rather than indicating stable sustainability, the moderate index score may signify a fragile equilibrium susceptible to external disturbances. Progressing toward transformative sustainability requires coordinated strengthening across social collaboration, technological upgrading, and institutional innovation.

5. Conclusions

This study critically investigates whether the moderate sustainability performance of smallholder cattle farming in Sinjai Regency reflects genuine structural stability or a concealed condition of systemic fragility. By employing the Social–Ecological–Technological Systems (SETS) framework and integrating a composite sustainability index with SWOT diagnostics, the analysis transcends descriptive scoring to offer a systemic interpretation of cross-dimensional alignment.

Although the overall sustainability index (2.77) categorizes the system as moderate, disaggregated results reveal an uneven internal configuration. The supporting function, characterized by strong farmer interest, resource availability, and baseline technical practices, constitutes a solid structural foundation. However, this foundational capacity has not been effectively converted into provisioning outcomes, particularly in terms of income generation, labor absorption, and cooperative strengthening. Similarly, while ecological and technological practices demonstrate partial adaptive capacity, the relatively weaker social dimension constrains collective upgrading and limits systemic integration.

These findings indicate that the system operates within a stable yet suboptimal equilibrium. Rather than signaling resilience, the moderate index score reflects constrained transformation: assets exist, but conversion efficiency across subsystems remains limited. In systems terms, technological and ecological components are progressing incrementally, yet institutional coordination and social capital formation lag behind, generating asymmetry in adaptive capacity. Such imbalance increases vulnerability to market volatility, feed price fluctuations, and environmental stress.

Therefore, advancing toward transformative sustainability requires more than incremental technical improvement. Policy interventions must prioritize cross-dimensional integration, strengthening farmer cooperation, institutional governance, innovation diffusion, and value-chain coordination so that social capital, ecological resources, and technological practices co-evolve rather than operate in parallel. Conceptually, this study reinforces the importance of interpreting sustainability as an emergent property of systemic coherence. Empirically, it demonstrates that in smallholder livestock contexts, moderate performance may mask structural fragility unless relational dynamics among subsystems are explicitly assessed.

Declarations

Ethics Approval and Consent to Participate

According to the institutional regulations of Universitas Hasanuddin, Makassar, Indonesia, formal ethical approval was not required for this study because the research involved a voluntary questionnaire survey of adult participants, did not involve medical interventions, biological samples, or sensitive personal data, and posed no more than minimal risk to participants. The study was conducted in accordance with applicable institutional ethical guidelines and the principles of the Declaration of Helsinki. Informed consent was obtained from all participants prior to data collection.

Consent to Participate

Informed consent was obtained from all individual participants included in this study before participation. All respondents voluntarily agreed to participate after receiving adequate information regarding the purpose, procedures, benefits, and confidentiality of the research. Participation was

entirely voluntary, and no personal identifying information was disclosed in any publication arising from this study.

Consent for Publication

Not applicable.

Competing Interests

The authors declare that they have no competing interests.

Ethics Statement

According to the Research Ethics Committee of Universitas Hasanuddin, ethical approval was waived for this study because the research involved a non-invasive questionnaire survey of adult participants and did not collect sensitive personal, medical, or biological data. The study was conducted in accordance with the ethical principles for research involving human participants and in accordance with the relevant institutional guidelines and regulations. Prior to participation, all respondents were informed about the purpose of the study, the voluntary nature of participation, and the confidentiality of their responses. Informed consent was obtained from all participants before data collection commenced.

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Data Availability Statement

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Author Contributions

Andi Suarda: Conceptualization, methodology, investigation, data collection, data curation, formal analysis, validation, visualization, project administration, writing, original draft preparation, and writing, review and editing.

Apitya Yamin: Conceptualization, methodology, supervision, validation, formal analysis, resources, writing, review and editing.

Rizal Akbar Aldyan: Literature review, data interpretation, visualization, validation, and writing, review and editing.

Hansen Tandra: Data analysis support, visualization, validation, and writing, review and editing.

All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Figures

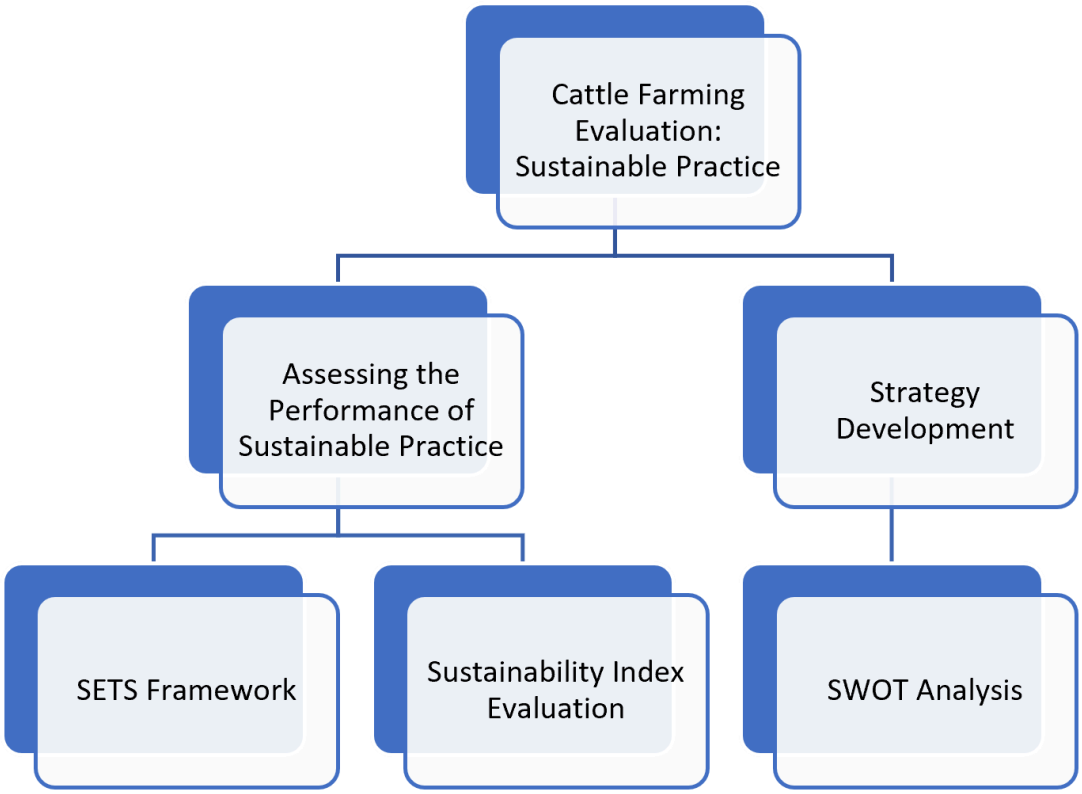


Figure 1

The Research Frawork

Source: Author Compilation (2026)



Figure 2

The Indicator of Sustainability Evaluation

Source: Author Compilation (2026)

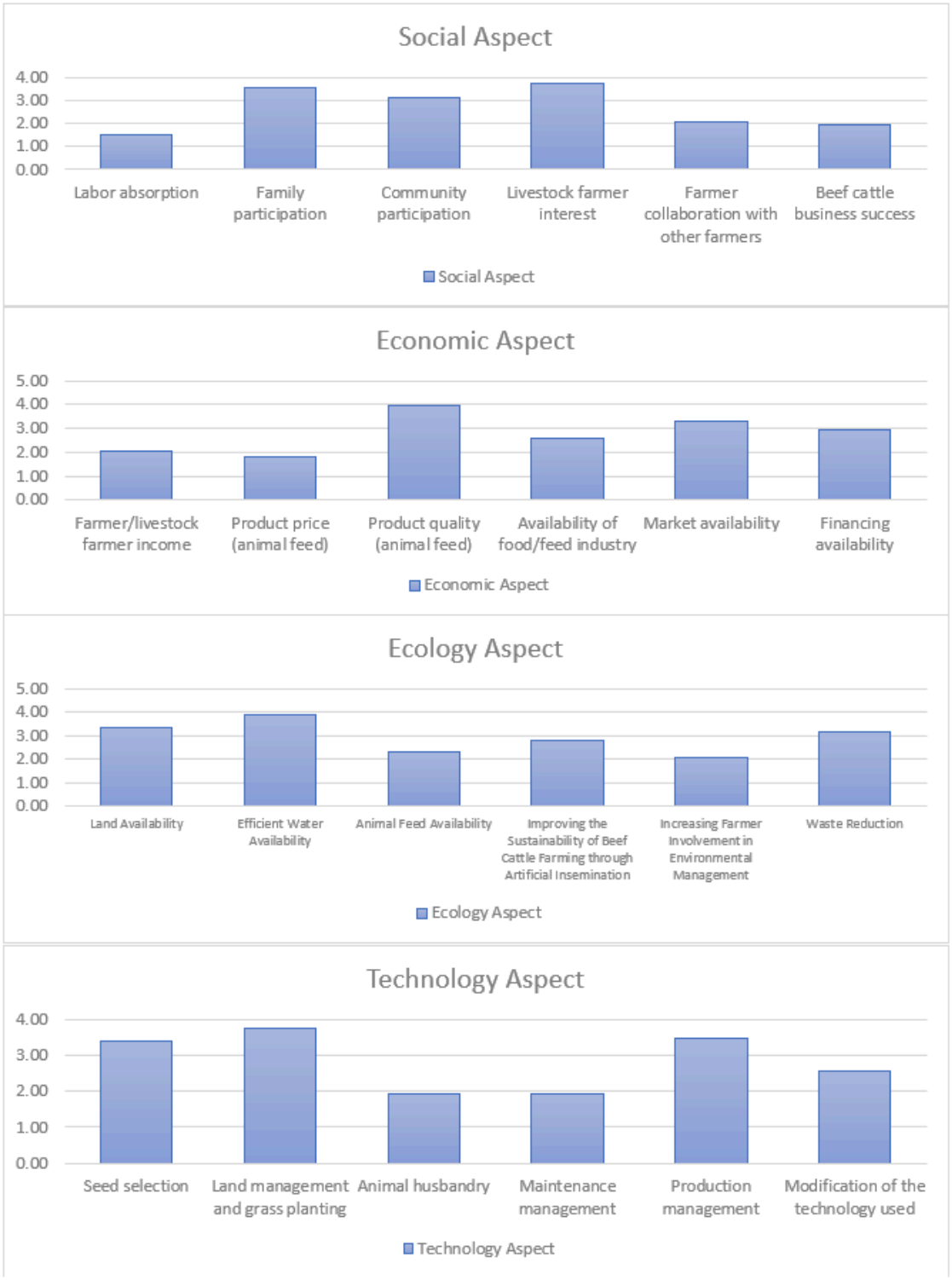


Figure 3

The Questionnaire Result of Sustainability Aspects

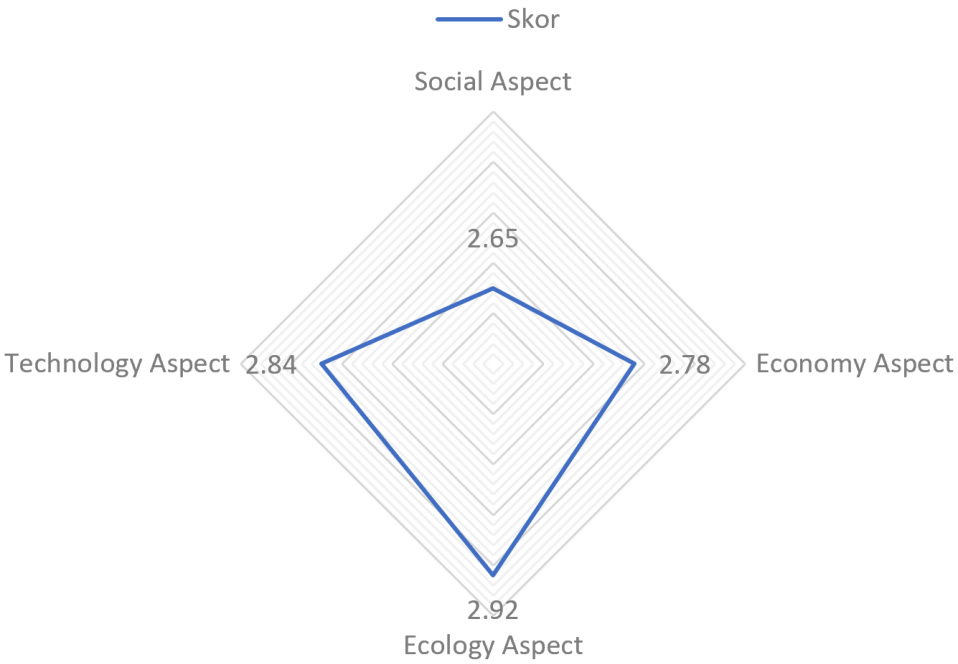


Figure 4

Spider Web Diagram of Sustainability Aspects in Cattle Farming

Source: Author Compilation (2026)