Building Resilience in Smallholder Dairy Farming: Integrating Enterprise Risk Management and Sustainability Dimensions in Indonesia

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Abstract.
Smallholder dairy farming plays a crucial role in rural livelihoods and food security in developing countries, yet it is highly exposed to multidimensional risks that threaten its sustainability. While previous studies have examined agricultural risks and sustainability separately, limited attention has been given to how these risks interact to shape system resilience and adaptive capacity. This study aims to analyze resilience in smallholder dairy farming by integrating Enterprise Risk Management (ERM) with a multidimensional sustainability framework. A case study was conducted in Suci Village, Jember Regency, Indonesia, involving 30 respondents, including farmers, cooperative representatives, and agricultural officers. Data were collected through focus group discussions, semi-structured interviews, and field observations. Risks were identified and assessed using an ERM-based risk register matrix, evaluated through likelihood and impact scoring. The results were subsequently reinterpreted using a resilience framework, linking risk exposure, sensitivity, and adaptive capacity. The findings reveal that most risks are concentrated in the high and extreme categories, indicating a structurally vulnerable system with low baseline resilience. Risks are highly interconnected across ecological, economic, social, and technological dimensions, generating cascading effects that amplify system instability. Technological limitations and weak institutional capacity were identified as key constraints to adaptive capacity, further increasing vulnerability to recurring shocks. This study contributes to the literature by extending ERM from a risk classification tool into a resilience-oriented analytical framework. By integrating risk management with sustainability dimensions, the study provides a novel approach to understanding and strengthening resilience in smallholder agribusiness systems. The findings offer practical implications for developing integrated, context-specific strategies to enhance long-term sustainability and adaptive capacity in smallholder dairy farming.

Keywords: *Smallholder dairy farming; resilience; enterprise risk management; sustainability and adaptive capacity multidimensional risk.*

I. INTRODUCTION

Smallholder dairy farming plays a strategic role in supporting rural livelihoods and national food security in developing countries. In Indonesia, particularly in East Java, dairy production is largely dominated by small-scale farmers who operate under resource constraints, limited technological access, and high exposure to environmental and market uncertainties. These conditions create a structurally vulnerable production system in which shocks such as feed scarcity, disease outbreaks, and price volatility can significantly disrupt both productivity and household income (Jan, 2020; Nguyen et al., 2022).

Existing literature has extensively examined agricultural sustainability through frameworks such as the Triple Bottom Line (TBL), emphasizing ecological, economic, and social dimensions. At the same time, studies on agricultural risk management have focused on identifying and mitigating specific risk factors, often using tools such as risk matrices or probabilistic models. However, these two streams of research remain largely disconnected. Sustainability studies tend to overlook how risks dynamically interact across dimensions, while risk management studies often fail to address how risk exposure influences long-term system resilience and adaptive capacity (Meena et al., 2024; Peñarrubia-Lozano et al., 2021).

The concept of resilience provides a critical bridge between these perspectives. Resilience refers to the ability of a system to absorb disturbances, adapt to changing conditions, and maintain its core functions over time. In the context of smallholder dairy farming, resilience is shaped not only by individual risks but also by the interaction between ecological constraints, economic pressures, social dynamics, and technological limitations. Despite its importance, empirical applications of resilience thinking in smallholder agribusiness systems remain limited, particularly in developing country contexts.

Enterprise Risk Management (ERM), as formalized in ISO 31000, offers a structured and integrative approach to identifying, assessing, and prioritizing risks across organizational dimensions. While ERM has been widely applied in corporate and large-scale agribusiness settings, its application in smallholder farming systems is still underexplored. More importantly, previous applications of ERM have predominantly focused on risk classification rather than leveraging it as a tool to understand systemic vulnerability and enhance resilience.

This study addresses these gaps by integrating ERM with a multidimensional sustainability framework to analyze resilience in smallholder dairy farming. Using a case study in Suci Village, Jember Regency, this research reinterprets risk classification results through a resilience lens, examining how risk exposure, interdependencies, and intensity shape the adaptive capacity of smallholder farmers. By incorporating ecological, economic, social, and technological dimensions into a unified analytical framework, this study provides a more comprehensive understanding of sustainability challenges in rural dairy systems.

The main contribution of this study lies in advancing the application of ERM beyond risk identification toward resilience-building analysis in smallholder agribusiness. Specifically, this research offers (1) an integrated framework linking risk exposure to system vulnerability and adaptive capacity, (2) empirical evidence on the multidimensional nature of risks in smallholder dairy farming, and (3) practical insights for developing simplified, context-specific risk management strategies that enhance long-term sustainability. In doing so, this study contributes to the growing body of literature on sustainable agriculture by bridging the gap between risk management and resilience thinking in developing-country contexts.

II. THEORITICAL BASIS

2.1. Sustainability in Smallholder Dairy Farming

Sustainability in dairy farming has been widely conceptualized using the Triple Bottom Line (TBL) framework, which emphasizes the integration of ecological, economic, and social dimensions. In smallholder systems, these dimensions are inherently interconnected and often constrained by limited resources and institutional capacity. Ecological sustainability focuses on resource efficiency, including feed availability, waste management, and environmental impacts such as greenhouse gas emissions. Economic sustainability relates to productivity, cost efficiency, market access, and income stability, while social sustainability encompasses farmer welfare, community relations, and institutional participation (Kilimani et al., 2020).

However, in developing-country contexts, sustainability challenges are rarely confined to a single dimension. Instead, they emerge from complex interactions among multiple factors. For example, feed scarcity not only affects ecological balance but also increases production costs and reduces farmer income, thereby linking ecological and economic vulnerabilities. Similarly, poor waste management can trigger social conflicts, indicating the interdependence between environmental practices and social acceptance. This multidimensional nature of sustainability necessitates an integrated analytical approach that goes beyond static indicators.

Recent studies have also highlighted the growing importance of technology as a critical enabler of sustainability in smallholder dairy systems. Technological interventions such as improved feeding systems, milk cooling infrastructure, and digital information platforms can significantly enhance productivity and reduce inefficiencies. As a result, technology is increasingly viewed as a cross cutting dimension that influences ecological performance, economic viability, and social inclusion simultaneously .

2.2. Agricultural Risk and Enterprise Risk Management (ERM)

Agricultural systems are inherently exposed to various types of risks, including production, market, financial, institutional, and environmental risks. In smallholder dairy farming, these risks are often amplified by limited access to capital, information asymmetry, and dependence on external inputs. Traditional approaches to agricultural risk management have primarily focused on individual risk factors, such as price volatility or disease outbreaks, often treating them as isolated phenomena.

Enterprise Risk Management (ERM) offers a more holistic approach by integrating risk identification, assessment, and mitigation within a unified framework. According to ISO 31000, ERM involves a systematic process of establishing context, identifying risks, analyzing likelihood and impact, and prioritizing responses. This approach allows for a structured understanding of risk exposure across multiple dimensions and facilitates better decision-making.

Despite its advantages, the application of ERM in smallholder farming systems remains limited. Most existing studies have applied ERM in corporate or large-scale agribusiness contexts, where formal organizational structures and data availability support its implementation. In contrast, smallholder systems require simplified, participatory, and context-specific adaptations of ERM to ensure practical relevance and usability.

Moreover, previous applications of ERM in agriculture have largely focused on risk classification and prioritization, without explicitly linking risk outcomes to broader sustainability or resilience objectives. This creates a gap in understanding how risk management frameworks can contribute to long term system stability and adaptive capacity.

2.3. Resilience and Adaptive Capacity in Agribusiness Systems

Resilience has emerged as a central concept in sustainability science, particularly in the context of systems exposed to uncertainty and shocks. In agribusiness, resilience refers to the ability of farming systems to absorb disturbances, reorganize, and continue functioning without significant loss of productivity or livelihood security. This concept extends beyond risk mitigation by emphasizing adaptation, learning, and transformation (German et al., 2020; Holland, 2020; Nishad et al., n.d.).

Resilience is commonly understood through three key components: exposure, sensitivity, and adaptive capacity. Exposure refers to the degree to which a system is subject to external shocks, such as climate variability or market fluctuations. Sensitivity reflects how strongly the system is affected by these shocks, while adaptive capacity represents the ability to adjust, respond, and recover.

In smallholder dairy farming, resilience is influenced by a combination of ecological conditions (e.g., feed availability), economic factors (e.g., price stability), social dynamics (e.g., cooperative participation), and technological capabilities (e.g., access to innovation). These factors interact in complex ways, meaning that resilience cannot be assessed by examining individual variables in isolation.

While resilience thinking has gained prominence, its empirical application in smallholder agribusiness remains relatively underdeveloped. Many studies rely on qualitative assessments or composite indices, with limited integration of structured risk assessment tools such as ERM. This suggests an opportunity to bridge resilience theory with risk management frameworks to provide more operational and data-driven insights.

2.4. Integrating ERM and Sustainability for Resilience Analysis

Integrating ERM with sustainability frameworks offers a promising approach to understanding and enhancing resilience in smallholder dairy systems. ERM provides a structured method for identifying and prioritizing risks, while sustainability frameworks capture the multidimensional nature of farming systems. By combining these approaches, it becomes possible to analyze not only what risks exist, but also how they interact and influence system vulnerability and adaptive capacity (Singh, 2020).

In this study, the integration is achieved by extending the TBL framework (ecological, economic, social) with a technological dimension and embedding it within an ERM-based risk assessment structure. Risks identified through the ERM process are mapped across these dimensions and analyzed based on their likelihood, impact, and interdependencies. This mapping enables the identification of systemic vulnerabilities, particularly where multiple high-impact risks converge.

More importantly, the ERM-based risk classification is reinterpreted through a resilience lens. High likelihood–high impact risks indicate areas of high exposure and sensitivity, while the absence or weakness of mitigation strategies reflects limited adaptive capacity. In this way, risk assessment becomes a tool not only for prioritization but also for diagnosing resilience gaps within the system.

2.5. Conceptual Framework: Risk–Vulnerability–Resilience Linkage

Based on the literature, this study proposes a conceptual framework that links risk exposure to resilience through the mediating role of system vulnerability.

Risk (ERM perspective): identified and measured through likelihood and impact

Vulnerability: shaped by exposure and sensitivity across sustainability dimensions

Resilience: reflected in the system's adaptive capacity and ability to sustain function

Within this framework:

Ecological, economic, social, and technological risks interact dynamically

Technology acts as a cross-cutting enabler that can reduce vulnerability or amplify risk

High-risk concentration signals low resilience and weak adaptive capacity

This integrated framework provides a more comprehensive analytical lens for understanding smallholder dairy sustainability, moving beyond static classification toward dynamic system analysis (Laouan, 2021; Potturu & Prasad, 2021; Zhang et al., 2020).

III. METHODS

3.1. Study Area and Research Design

This study was conducted in Suci Village, Panti District, Jember Regency, East Java, Indonesia, a region characterized by smallholder based dairy farming systems integrated with local cooperative structures. The area represents a typical rural agribusiness context in developing countries, where farmers operate under resource constraints and are highly exposed to environmental and market uncertainties.

A case study approach was employed to enable an in-depth analysis of risk dynamics and resilience in a real-world setting. This approach is particularly suitable for examining complex, context specific interactions among ecological, economic, social, and technological factors that shape sustainability outcomes in smallholder systems.

3.2. Data Collection

The study utilized a mixed methods approach combining qualitative and semi-quantitative data collection techniques to capture both experiential and measurable aspects of risk and resilience.

Primary data were collected through:

Focus Group Discussions (FGDs): conducted with dairy farmers to identify and validate key risks across sustainability dimensions.

Semi-structured interviews: with farmers, cooperative representatives, and agricultural officers to explore risk perception, management practices, and adaptive strategies.

Field observations: to document farming practices, technological conditions, and environmental issues.

A total of 30 respondents participated in the study, representing a cross-section of stakeholders within the dairy farming system.

Secondary data were obtained from:

cooperative records, agricultural office reports, and relevant scientific literature.

3.3. Analytical Framework: ERM-Based Risk Assessment

Risk analysis in this study followed the principles of **Enterprise Risk Management (ERM)** based on ISO 31000:2018. The analytical process consisted of four main stages:

1. **Establishing context:** defining the scope of analysis across the dairy value chain (input, production, post-harvest, and marketing) and identifying sustainability dimensions (ecological, economic, social, technological).
2. **Risk identification:** compiling potential risks through FGDs, interviews, and observations.
3. **Risk assessment:** evaluating each identified risk using two parameters:

Likelihood (L): probability of occurrence

Impact (I): severity of consequences

Each parameter was measured using a **four-point ordinal scale** (1 = low, 2 = moderate, 3 = high, 4 = extreme).

4. **Risk prioritization:** constructing a **risk register matrix (heatmap)** to classify risks into categories based on combined likelihood–impact scores.

3.4. Reframing Risk Assessment for Resilience Analysis

To move beyond conventional risk classification, the ERM results were **reinterpreted using a resilience framework**. Specifically, the study links risk assessment outcomes to three key components of system resilience:

Exposure: represented by the likelihood of risk occurrence
Sensitivity: represented by the magnitude of impact
Adaptive capacity: inferred from farmers' ability to manage, mitigate, or respond to identified risks
Risks located in the high likelihood–high impact quadrant were interpreted as indicators of high vulnerability, reflecting both strong exposure and high sensitivity. Conversely, the presence of mitigation practices, technological support, or institutional mechanisms was used to assess adaptive capacity.
This reinterpretation allows the risk register matrix to function not only as a prioritization tool but also as a diagnostic instrument for evaluating system resilience**.**

3.5. Multidimensional Risk Mapping

Identified risks were categorized into four sustainability dimensions:
Ecological: feed scarcity, waste management, environmental pollution
Economic: input cost volatility, milk price instability, productivity constraints
Social: community conflict, cooperative participation, governance issues
Technological: infrastructure limitations, low adoption of innovation, digital gaps
Each risk was mapped across these dimensions to analyze cross dimensional **interactions**. This mapping enables the identification of systemic risks, where a single issue triggers cascading effects across multiple sustainability domains.

3.6. Data Interpretation and Validation

The interpretation of results emphasized:
the distribution of risks across the matrix, the concentration of high-priority risks,
and the interdependencies among sustainability dimensions.
To enhance reliability, findings were validated through:
triangulation of data sources (FGDs, interviews, observations), and expert judgment, involving agricultural officers and cooperative representatives.

IV. RESULTS AND DISCUSSION

4.1. Concentration of High Intensity Risks and Structural Vulnerability

The ERM analysis indicates a disproportionate concentration of risks in the high and extreme categories, reflecting a non random distribution of risk exposure. This clustering suggests that smallholder dairy farming in Suci Village is not merely exposed to multiple risks, but is structurally positioned in a high risk equilibrium, where disturbances are both frequent and severe.

Such a configuration implies that shocks whether ecological (feed scarcity), economic (input price volatility), or technological (infrastructure limitations) are not absorbed effectively but instead propagate through the system. From a resilience standpoint, this indicates low absorptive capacity, meaning the system is unable to maintain stability under stress.

This finding extends previous risk classification studies by demonstrating that the distribution pattern of risks itself is a diagnostic indicator of systemic fragility, rather than just a descriptive outcome.

4.2. Risk Interdependencies and Cascading Failure Mechanisms

A key finding of this study is the presence of strong interdependencies among risks, which generate cascading effects across sustainability dimensions. The system exhibits characteristics of coupled risks, where the occurrence of one risk significantly increases the probability and impact of others.
For example:
Feed scarcity (ecological) → increases reliance on purchased feed → raises production costs (economic)
Rising costs → reduce farmers' financial flexibility → limit investment in technology (technological)
Poor waste handling → triggers community complaints → escalates into social conflict (social)

These linkages indicate that risks function within a feedback loop structure, where initial disturbances amplify over time. This aligns with the concept of systemic risk, commonly discussed in complex systems theory, where localized failures can trigger broader system instability (Ford & Forsyth, 2021; Kolageri & Banakar, n.d.; Nar & Nar, 2020).

Importantly, this implies that conventional risk mitigation strategies focused on isolated interventions are insufficient. Instead, resilience requires breaking these feedback loops through integrated and cross-sectoral interventions.

4.3. Technological Deficit as a Bottleneck in Adaptive Capacity

The analysis identifies technological limitations as a critical bottleneck that constrains the system's adaptive capacity. Unlike ecological and economic risks, which are often external or semi-controllable, technological capacity represents an internal leverage point that can significantly alter system behavior.

The absence of adequate cooling systems, low adoption of digital tools, and limited access to innovation reduce the system's ability to:

respond to market signals, maintain product quality, and implement efficient production practices.

This creates a condition where even moderate disturbances lead to disproportionate losses, indicating high sensitivity combined with low adaptability.

From a resilience perspective, technology acts as a multiplier variable:

When weak → amplifies vulnerability

When strengthened → enhances recovery and transformation capacity

Thus, technological upgrading should be viewed not as a supplementary intervention but as a core resilience strategy.

4.4. Institutional Weakness and Social Fragility

Beyond biophysical and economic factors, the study reveals that institutional and social dynamics significantly influence resilience outcomes. Weak cooperative participation and limited collective coordination reduce the system's ability to respond to shared risks.

In resilient systems, institutions function as:

coordinators of collective action, distributors of resources, and stabilizers during shocks. However, in the studied context, institutional limitations result in fragmented responses, where farmers act individually rather than collectively. This reduces efficiency in risk mitigation and weakens overall system resilience. Additionally, social conflicts arising from environmental externalities (e.g., waste-related odor) indicate a misalignment between production practices and community expectations. Such conflicts not only threaten social sustainability but also create indirect economic and regulatory risks (Karimi et al., 2020; Nathaniel & Bekun, 2020).

4.5. Reinterpreting ERM as a Resilience Diagnostic Tool

This study demonstrates that ERM, when extended beyond its conventional function, can serve as a resilience diagnostic framework. Rather than merely ranking risks, the likelihood–impact matrix can be interpreted as a representation of:

Exposure (likelihood dimension), Sensitivity (impact dimension), Adaptive capacity (inferred from mitigation readiness)

Through this reinterpretation, the ERM matrix provides insight into:

where the system is most vulnerable, how risks are interconnected, and which areas lack sufficient adaptive mechanisms.

This approach contributes methodologically by transforming a static risk assessment tool into a dynamic system analysis instrument, bridging the gap between risk management and resilience theory.

4.6. Toward Integrated Resilience-Building Strategies

The findings suggest that improving resilience requires a systemwide transformation, rather than incremental adjustments. Key strategic directions include:

Ecological domain: development of local feed resources and sustainable waste management systems

Economic domain: diversification of income sources and strengthening of market linkages

Social domain: enhancement of cooperative governance and conflict mediation mechanisms

Technological domain: expansion of access to appropriate technologies and digital platforms

Crucially, these interventions must be implemented in an integrated manner, as improvements in one domain will influence outcomes in others. This reinforces the importance of adopting a systems approach in designing policies and interventions for smallholder dairy farming.

V. CONCLUSION

This study demonstrates that smallholder dairy farming systems in developing-country contexts are characterized by high exposure to multidimensional risks**,** which collectively shape system vulnerability and limit long-term sustainability. The ERM based analysis reveals a strong concentration of risks in the high and extreme categories, indicating that disturbances are not only frequent but also severe and systemic in nature.

More importantly, the findings highlight that risks in smallholder dairy farming are highly interconnected across ecological, economic, social, and technological dimensions**,** forming cascading effects that amplify overall system instability. This confirms that sustainability challenges cannot be adequately addressed through single-dimensional or isolated interventions.

By reinterpreting ERM through a resilience framework, this study shows that:

likelihood reflects risk exposure, impact reflects system sensitivity, and mitigation capacity reflects adaptive capacity.

The combination of high exposure, high sensitivity, and limited adaptive capacity results in a low resilience system, where farmers are highly vulnerable to recurring shocks.

The main contribution of this study lies in advancing the application of ERM from a conventional risk classification tool into a resilience oriented analytical framework. By integrating ERM with a multidimensional sustainability perspective (ecological, economic, social, and technological), this research provides a novel approach to understanding how risk structures influence system vulnerability and adaptive capacity in smallholder agribusiness.

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