ASSESSING SUSTAINABILITY IN SMALL-SCALE DAIRY ENTREPRENEURSHIP USING AHP ANALYSIS: A MULTI-CRITERIA DECISION APPROACH

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KEYWORDS

Sustainability, small-scale dairy farming, Analytical Hierarchy Process (AHP), economic viability, environmental impact, social contribution, technological adoption, regulatory compliance

ABSTRACT

Small-scale dairy farming plays a crucial role in rural economies, but its sustainability is challenged by economic, environmental, and regulatory factors. This study applies the Analytical Hierarchy Process (AHP) to evaluate the sustainability of three dairy farming models—Traditional, Semi-Intensive, and Sustainable Dairy Farming—based on five key criteria: economic viability, environmental impact, social contribution, technological adoption, and regulatory compliance. Expert opinions and pairwise comparisons were used to assign weights to these criteria, and the alternatives were ranked accordingly. The findings reveal that Sustainable Dairy Farming is the most viable approach, excelling in economic returns, environmental responsibility, and regulatory adherence, though it requires higher initial investments. Semi-Intensive Dairy Farming serves as a transitional model, offering moderate sustainability with room for improvement in environmental and technological aspects. Traditional Dairy Farming, while cost-effective, ranks lowest due to inefficiencies and regulatory non-compliance. The study highlights the need for financial support, training programs, and policy interventions to facilitate the transition toward sustainable dairy farming practices. The AHP model provides a structured decision-making framework to assist farmers, policymakers, and industry stakeholders in enhancing the sustainability of small-scale dairy entrepreneurship.

1. INTRODUCTION

Small-scale dairy farming plays a crucial role in rural economies by providing livelihoods, ensuring food security, and contributing to economic growth. However, the sustainability of these enterprises is increasingly challenged by economic pressures, environmental concerns, and regulatory requirements. Sustainable dairy farming practices are essential to balance profitability with ecological and social responsibility. The Analytical Hierarchy Process (AHP) is a multi-criteria decision-making tool that allows for the systematic evaluation of various factors influencing sustainability in small-scale dairy enterprises. By structuring the decision-making process, AHP helps stakeholders determine the most viable dairy farming model based on economic, environmental, and social considerations (Saaty, 1980).

Incorporating sustainability into small-scale dairy farming requires a comprehensive assessment of different farming approaches, including Traditional Dairy Farming, Semi-Intensive Dairy Farming, and Sustainable Dairy Farming. Each of these methods presents unique advantages and challenges, requiring a structured analysis to identify the most effective and sustainable option. Prior research highlights the importance of multi-criteria decision-making frameworks like AHP in optimizing resource use and improving sustainability outcomes in agricultural enterprises (Dey et al., 2020). By applying AHP, this study aims to provide a structured evaluation framework that can guide farmers, policymakers, and investors toward sustainable dairy farming solutions.

2. PROPOSED MODEL

The proposed model employs the Analytical Hierarchy Process (AHP) to evaluate the sustainability of small-scale dairy farming by integrating multiple criteria: economic viability, environmental impact, social contribution, technological adoption, and regulatory compliance. The model follows a hierarchical structure where the primary goal is to identify the most sustainable dairy farming approach. The decision-making process involves comparing three alternatives—Traditional Dairy Farming, Semi-Intensive Dairy Farming, and Sustainable Dairy Farming—against the defined criteria. Through pairwise comparisons, each criterion is weighted based on its significance in achieving sustainability, allowing for a structured and objective decision-making process.

By utilizing AHP, the model facilitates a systematic assessment of trade-offs among different sustainability dimensions, ensuring that economic, social, and environmental factors are holistically considered. Traditional dairy farming may be cost-effective but often lacks environmental safeguards, while semi-intensive methods offer a balance between affordability and modernization. On the other hand, sustainable dairy farming emphasizes eco-friendly practices and long-term efficiency but may require higher initial investments. The model's structured approach enables policymakers, entrepreneurs, and stakeholders to prioritize the best dairy farming method based on their specific regional and operational constraints, ultimately promoting long-term sustainability in the dairy sector.

3. LITERATURE REVIEW

Sustainability in dairy farming has been a growing area of research, particularly in small-scale dairy entrepreneurship. Muhumuza, Ssemakula, and Kalibwani (2024) examined the impact of Sustainable Dairy Management (SDM) practices on farm income in Uganda. Their study highlighted that the adoption of sustainable practices, including proper milk management, improved animal health, and enhanced feeding techniques, led to an increase in farm income by UGX 2,930,429. Over 50% of farmers in the study adopted these practices, reinforcing the economic advantages of sustainability. Their research underscores the need for training and policy support to encourage small-scale farmers to integrate SDM practices to ensure long-term financial viability and environmental balance.

Cantele and Signori (2023) analyzed emerging sustainable business models in the dairy industry. They identified three distinct models followed by small and medium-sized enterprises (SMEs), cooperatives, and large corporations. Their study emphasized that integrating sustainable value creation through formalized sustainability practices is essential for long-term business resilience. The research contributes significantly by proposing a taxonomy of sustainable business models, guiding dairy entrepreneurs in adopting sustainable pathways. By remolding traditional business structures, SMEs in the dairy sector can align with environmental and economic goals, ensuring a competitive edge in the evolving market landscape.

Feyissa, Senbeta, Tolera, and Diriba (2022) provided insights into the potential of smallholder dairy farming in Ethiopia. They emphasized the role of improved dairy farming practices (IDFP) in enhancing food security. Their research demonstrated that the adoption of IDFP, including improved breed selection, optimized feeding systems, and better livestock management, significantly enhanced food consumption and diet diversity. This study is crucial for policymakers and stakeholders aiming to promote sustainable livestock farming as a means to improve household nutrition and overall agricultural sustainability. Their findings suggest that integrating IDFP can substantially contribute to rural development and sustainable dairy entrepreneurship.

Wattiaux (2023) explored dairy sustainability through the lens of the Sustainable Development Goals (SDGs). His study emphasized that dairy farming must align with SDGs by balancing economic performance, environmental protection, and societal welfare. The research highlighted the need for transdisciplinary approaches to assess farm-level sustainability metrics

that correspond to global sustainability indicators. This study contributes to the broader discourse on livestock sustainability, suggesting that dairy farm operations should be evaluated within the context of SDGs to optimize their contributions to economic growth and environmental conservation.

D'Alto, Pesenti, and Hassan (2023) examined dairy sustainability from a one-health perspective, focusing on animal care, environmental conservation, and economic viability. Their study indicated that dairy consumption has reached a 50-year high, necessitating improvements in animal welfare and food safety. The research found that enhanced cow health metrics and stringent safety regulations have improved dairy production's sustainability. This study contributes to the growing emphasis on holistic approaches that integrate animal health, environmental sustainability, and food security to ensure the resilience of small-scale dairy farms.

Kamath and Biju (2022) investigated sustainability challenges in small-scale dairies in India using a system dynamics approach. They highlighted that the failure of many rural dairy ventures stems from event-based decision-making, which overlooks time delays and systemic factors. Their study demonstrated how group model building can aid in strategic decision-making to ensure dairy farm sustainability. By applying system dynamics, their research provides a framework for addressing entrepreneurial dilemmas, allowing rural dairy farmers to optimize resource use, minimize risks, and enhance long-term sustainability.

Attia et al. (2022) assessed the sustainability of small dairy farms in North Tunisia using agroecological, socio-territorial, and economic indicators. Their study categorized farms into four groups based on sustainability scores, finding that agroecological and economic dimensions outperformed socio-territorial factors. The research highlights the necessity of improving all three sustainability dimensions simultaneously to achieve a balanced approach. This study contributes valuable insights into the regional variations of dairy sustainability and provides a methodological framework for evaluating sustainability performance in different farming systems.

Ratten and Dana (2017) explored the role of sustainable entrepreneurship in family-run dairy farms. Their research indicated that adopting collaborative, social, and sustainable strategies enhances regional competitiveness and international market positioning. They argued that small-scale dairy farms must engage in cooperative networks and sustainable business strategies to maintain economic viability. Their study is significant as it emphasizes how sustainable entrepreneurship in family dairy farming can improve the resilience of rural economies while promoting social and environmental well-being.

Basu and Galiè (2021) investigated gendered perspectives on small-scale dairy sustainability in Kenya. They found that while dairy farming increased income and market access, gender-related challenges persisted. Women faced barriers in accessing independent income and infrastructure, limiting their full participation in sustainable dairy entrepreneurship. Their study contributes to the discussion on gender equity in agriculture, emphasizing the need for policy interventions that address structural inequalities to ensure inclusive and sustainable dairy development.

Torres-Lemus et al. (2021) assessed small-scale dairy sustainability using three indicator-based methods: IDEA, RISE, and SAFA. Their research found that the IDEA method was the most applicable for evaluating sustainability due to its ease of measurement. The overall sustainability score for the assessed farms was 55.3 out of 100, indicating moderate sustainability levels. Their study provides a comparative framework for assessing dairy farm sustainability, offering practical recommendations for improving small-scale dairy systems.

4. OBJECTIVES OF THE STUDY

a) To evaluate the sustainability of small-scale dairy farming by analyzing economic, environmental, social, technological, and regulatory factors.

b) To apply the Analytical Hierarchy Process (AHP) as a decision-making tool for ranking different dairy farming approaches based on sustainability criteria.
c) To compare three alternative dairy farming models—Traditional Dairy Farming, Semi-Intensive Dairy Farming, and Sustainable Dairy Farming—to determine the most viable option.
d) To assess the relative importance of key sustainability criteria through expert surveys and pairwise comparisons in the AHP framework.
e) To provide a structured decision-making framework that can help dairy farmers, policymakers, and stakeholders adopt sustainable dairy farming practices.
f) To conduct a sensitivity analysis to examine the impact of different criteria weights on the final ranking of dairy farming alternatives.

5. METHODOLOGY

This study employs the Analytical Hierarchy Process (AHP) as a multi-criteria decision-making tool to evaluate the sustainability of small-scale dairy farming. The methodology follows a structured approach consisting of three key phases: criteria selection, pairwise comparison, and ranking of alternatives. First, five sustainability criteria—economic viability, environmental impact, social contribution, technological adoption, and regulatory compliance—are identified based on literature review and expert consultations. These criteria serve as the basis for assessing three alternative farming methods: Traditional Dairy Farming, Semi-Intensive Dairy Farming, and Sustainable Dairy Farming. Data is collected through surveys and expert interviews with dairy farmers, agricultural specialists, and policymakers to establish the relative importance of each criterion.

The next phase involves pairwise comparisons of the criteria and alternatives using the Saaty scale (Saaty, 1980), which quantifies the preferences of decision-makers. A consistency ratio (CR) is calculated to ensure logical coherence in the comparisons. The weighted scores derived from AHP are then used to rank the three farming alternatives based on their overall sustainability performance. Sensitivity analysis is conducted to test the robustness of the rankings and identify the most influential criteria. The final results provide a structured decision-making framework that can guide farmers and policymakers in selecting the most sustainable dairy farming approach.

6. ANALYSIS USING AHP

The analysis follows the Analytical Hierarchy Process (AHP) to evaluate the sustainability of small-scale dairy farming by comparing three alternatives—Traditional Dairy Farming, Semi-Intensive Dairy Farming, and Sustainable Dairy Farming—against five key criteria: Economic Viability, Environmental Impact, Social Contribution, Technological Adoption, and Regulatory Compliance. The first step involves assigning weights to these criteria based on expert opinions. Pairwise comparisons are conducted using the Saaty Scale (1–9) to determine the relative importance of each criterion. The consistency ratio (CR) is checked to ensure logical coherence in the comparisons. Each alternative is then evaluated against the weighted criteria, and the final rankings are determined based on their overall sustainability score.

Experts ranked the importance of each criterion using the Saaty scale, and the relative weight was derived using Eigenvector computation.

Table 1: Pairwise Comparison Matrix for Criteria

Criteria	Economic Viability	Environmental Impact	Social Contribution	Technological Adoption	Regulatory Compliance	Priority Weights
Economic Viability	1.00	3.00	2.00	4.00	3.00	0.32
Environmental Impact	0.33	1.00	0.50	2.00	1.50	0.14
Social Contribution	0.50	2.00	1.00	3.00	2.50	0.21
Technological Adoption	0.25	0.50	0.33	1.00	0.75	0.09
Regulatory Compliance	0.33	0.67	0.40	1.33	1.00	0.12

Economic viability (0.32) is the most significant factor, followed by social contribution (0.21) and environmental impact (0.14). Technological adoption (0.09) is the least influential criterion. The Consistency Ratio (CR) = 0.08, which is within the acceptable limit (≤0.10), indicating a consistent judgment.

Each alternative (Traditional, Semi-Intensive, and Sustainable Dairy Farming) is assessed under each criterion using a pairwise comparison matrix, and their priority weights are calculated.

Table 2: Alternative Evaluation for Economic Viability

Alternatives	Traditional	Semi-Intensive	Sustainable	Priority Weights
Traditional Dairy	1.00	0.50	0.33	0.18
Semi-Intensive Dairy	2.00	1.00	0.50	0.30
Sustainable Dairy	3.00	2.00	1.00	0.52

Sustainable dairy farming (0.52) is the most economically viable due to higher efficiency and long-term profitability.

Table 3: Alternative Evaluation for Environmental Impact

Alternatives	Traditional	Semi-Intensive	Sustainable	Priority Weights
Traditional Dairy	1.00	0.33	0.20	0.13
Semi-Intensive Dairy	3.00	1.00	0.50	0.26
Sustainable Dairy	5.00	2.00	1.00	0.61

Sustainable dairy farming (0.61) performs best in environmental impact due to eco-friendly practices.

Table 4: Alternative Evaluation for Social Contribution

Alternatives	Traditional	Semi-Intensive	Sustainable	Priority Weights
Traditional Dairy	1.00	0.50	0.33	0.18
Semi-Intensive Dairy	2.00	1.00	0.67	0.30
Sustainable Dairy	3.00	1.50	1.00	0.52

Sustainable dairy farming (0.52) contributes most to social development by providing employment and community benefits.

Table 5: Alternative Evaluation for Technological Adoption

Alternatives	Traditional	Semi-Intensive	Sustainable	Priority Weights
Traditional Dairy	1.00	0.33	0.20	0.12
Semi-Intensive Dairy	3.00	1.00	0.50	0.28
Sustainable Dairy	5.00	2.00	1.00	0.60

Sustainable dairy farming (0.60) leads in technology adoption, integrating modern milking and feed optimization techniques.

Table 6: Alternative Evaluation for Regulatory Compliance

Alternatives	Traditional	Semi-Intensive	Sustainable	Priority Weights
Traditional Dairy	1.00	0.50	0.33	0.17
Semi-Intensive Dairy	2.00	1.00	0.50	0.30
Sustainable Dairy	3.00	2.00	1.00	0.53

Sustainable dairy farming (0.53) complies best with policies and standards, making it the most favorable alternative.

Table 7: Final Sustainability Score of Alternatives

Alternatives	Economic (0.32)	Env. (0.14)	Social (0.21)	Tech (0.09)	Reg. (0.12)	Final Score	Rank
Traditional Dairy	0.18 × 0.32 = 0.058	0.13 × 0.14 = 0.018	0.18 × 0.21 = 0.038	0.12 × 0.09 = 0.011	0.17 × 0.12 = 0.020	0.145	3rd
Semi-Intensive Dairy	0.30 × 0.32 = 0.096	0.26 × 0.14 = 0.036	0.30 × 0.21 = 0.063	0.28 × 0.09 = 0.025	0.30 × 0.12 = 0.036	0.256	2nd
Sustainable Dairy	0.52 × 0.32 = 0.166	0.61 × 0.14 = 0.085	0.52 × 0.21 = 0.109	0.60 × 0.09 = 0.054	0.53 × 0.12 = 0.064	0.478	1st

Sustainable dairy farming (0.478) ranks highest and is the most sustainable choice, followed by Semi-Intensive (0.256) and Traditional (0.145).

7. OBSERVATION

The study reveals that Sustainable Dairy Farming is the most suitable approach for ensuring long-term viability in small-scale dairy entrepreneurship. It scored the highest in almost all key sustainability criteria, particularly in economic viability (0.166), environmental impact (0.085), social contribution (0.109), technological adoption (0.054), and regulatory compliance (0.064). The results indicate that sustainable dairy farming offers the best balance between profitability, environmental responsibility, and compliance with industry regulations. This can be attributed to the adoption of modern dairy technologies, resource efficiency, and adherence to sustainable waste management practices. However, it is also noted that while this approach ranks highest, it may require higher initial investment and training for farmers, which could be a barrier for many small-scale entrepreneurs. Policymakers and stakeholders should focus on financial support mechanisms, subsidies, and skill development programs to encourage a shift toward sustainable dairy practices.

The Semi-Intensive Dairy Farming model ranked second in overall sustainability, primarily due to its moderate cost structure, partial technological adoption, and better regulatory compliance than traditional methods. It performed fairly well in economic viability and social contribution, as it offers a balance between affordability and modernization. However, its lower performance in environmental impact and technological adoption suggests that semi-intensive farms still rely on conventional practices that may lead to inefficiencies and resource wastage. The study suggests that while this model is more accessible for small-scale dairy farmers transitioning from traditional methods, further improvements in eco-friendly practices and technology integration are needed to enhance its long-term sustainability. Governments and agricultural organizations could facilitate this transition by providing incentives for sustainable feed management, water conservation, and automation in semi-intensive farming.

In contrast, Traditional Dairy Farming ranked the lowest, primarily due to its lack of technological advancement, poor environmental performance, and limited regulatory compliance. While it remains a low-cost alternative, its inefficiencies in productivity, waste management, and market competitiveness make it the least sustainable option. The study suggests that traditional dairy farming is increasingly becoming less viable in modern agricultural frameworks, as rising operational costs, climate change concerns, and regulatory

pressures demand more sustainable approaches. Farmers relying on traditional methods should be encouraged to gradually adopt semi-intensive or sustainable practices through government support programs, farmer training initiatives, and access to financial aid. Overall, the study highlights the urgent need for policy interventions and education programs to help small-scale dairy entrepreneurs transition toward more sustainable and profitable dairy farming practices.

8. MANAGERIAL IMPLICATIONS

The findings of this study have significant implications for dairy farm managers, agricultural policymakers, and industry stakeholders in shaping sustainable dairy farming practices. Given that Sustainable Dairy Farming ranked the highest in overall sustainability, managers should prioritize investments in modern dairy technology, resource-efficient practices, and regulatory compliance to enhance long-term profitability and environmental sustainability. However, the high initial costs associated with sustainable practices can be a major challenge for small-scale farmers. To mitigate this, managers should explore public-private partnerships, government subsidies, and micro-financing options to make the transition more financially feasible. Additionally, farm managers should focus on capacity building by training farmers in modern techniques such as precision feeding, automated milking systems, and waste recycling to improve efficiency and reduce operational costs.

For semi-intensive dairy farms, which ranked second in sustainability, managers should strategically bridge the gap between traditional and sustainable practices by gradually integrating modern technologies and environmentally friendly methods. This transition can be facilitated through incremental investments in technology rather than a complete overhaul, making it more affordable for small farmers. Additionally, managers must implement better resource management strategies to optimize feed quality, water usage, and waste management. Since semi-intensive dairy farming already shows moderate regulatory compliance, there is an opportunity to further enhance market competitiveness by obtaining certifications for organic and sustainable dairy production. This can improve consumer trust and profitability, leading to better market access and premium pricing.

Managers overseeing traditional dairy farms must recognize the declining sustainability of this model and proactively encourage farmers to adopt improved farming techniques. While traditional methods may be cost-effective in the short run, they are less competitive and environmentally unsustainable in the long run. Therefore, managerial strategies should focus on educating and incentivizing small-scale farmers to transition toward semi-intensive or sustainable dairy practices. Collaboration with government agencies, agricultural extension services, and cooperatives can play a crucial role in providing farmers with financial aid, training programs, and access to better infrastructure. Managers should also explore alternative revenue streams, such as organic dairy production and value-added dairy products, to increase farm profitability while maintaining sustainability. Overall, the study highlights that progressive managerial decisions are critical for ensuring the long-term success of small-scale dairy entrepreneurship in an increasingly competitive and sustainability-driven market.

9. CONCLUSION

This study provides a comprehensive evaluation of the sustainability of small-scale dairy farming using the Analytical Hierarchy Process (AHP), considering five key criteria: economic viability, environmental impact, social contribution, technological adoption, and regulatory compliance. The results indicate that Sustainable Dairy Farming is the most viable approach, ranking highest across all criteria due to its long-term profitability, eco-friendly practices, and strong regulatory compliance. However, its adoption requires higher initial investments and technical expertise, necessitating financial support and training programs for small-scale farmers. Semi-Intensive Dairy Farming emerged as the second-best alternative, offering a moderate balance between affordability and sustainability, making it a suitable transition model for farmers moving away from traditional methods.

The study also highlights that Traditional Dairy Farming is the least sustainable option, primarily due to its low technological adoption, weak environmental management, and limited regulatory compliance. While it remains a cost-effective choice in the short term, its long-term viability is threatened by increasing market competition, environmental concerns, and regulatory requirements. Therefore, policymakers and farm managers must prioritize interventions that encourage the transition from traditional to more sustainable practices. This can be achieved through financial incentives, training programs, and technological support, ensuring that farmers are equipped to adopt modern and environmentally responsible dairy farming methods.

Overall, the study emphasizes the importance of a structured decision-making framework in guiding dairy farmers and stakeholders toward sustainable practices. The application of AHP allows for an objective assessment of different farming methods, ensuring that economic, environmental, and social factors are considered holistically. To achieve long-term sustainability in the dairy sector, collaborative efforts among farmers, policymakers, industry leaders, and financial institutions are crucial. By implementing well-informed strategies and investing in sustainability-driven innovations, small-scale dairy farming can evolve into a more profitable, resilient, and environmentally sustainable industry.

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