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Factors Affecting Sustainability in the Smallholder Dairy Farming in Bangladesh: Using A Tripple-Bottom-Line the Effect of Engagement as Mediator and Policy as Moderator

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Abstract: The global population is growing, with Bangladesh set to reach 300 million people by 2050, up from 165 million. This puts significant strain on resources like dairy, nutrition, and food. Smallholder farmers currently provide 80% of whole milk, but their need for increased output threatens the environment. Sustainable dairy farming, beneficial for economics, society, and the planet, is challenging for these farmers due to their socioeconomic circumstances. This study addressed this issue by evaluating the impact of economic, social, and environmental factors on sustainable dairy farming, employing the Total-Bottom-Line Model, with engagement as a mediator and policy as a moderator. The study, a case study on PRAN Dairy Limited in Bangladesh, used a mixed-method approach, combining quantitative and qualitative research. Findings showed that economic and social factors, mediated by engagement, significantly affect sustainable dairy farming. Environmental factors, mediated by engagement, were not significant, and policy as a moderator had no significant impact. This research provides valuable insights for stakeholders, but future studies should expand the scope and sample size for more comprehensive results.

Keywords Smallholder Farmer, Sustainable Dairy Farming, Triple Bottom Line, Engagement, Policy, Private Dairy Processor, Contract Farming.

1. Introduction

The global population is experiencing unparalleled growth and is projected to reach between 9.7 and 10 billion population by the year 2050 [1, 2]. The evolution of dietary habits tends to follow at a slower pace compared to advancements in agriculture, food science, and dairy production, resulting in a projected 22% increase in the demand for milk within the coming decade [3]–[7]. Sustaining the supply chain for consumers and dairy processors hinges upon the prolonged milk output of smallholder dairy farmers, who are the primary contributors, yet this extension of production presents a dual challenge: the environmental impact of dairy farming necessitates

assistance from stakeholders for its expansion, requiring the adoption of sustainable dairy farming practices that encompass economic viability, social equity, and environmental conservation. Establishing a sustainable market for smallholder dairy farmers necessitates collaboration among the government, private sector, and NGOs through multi-stakeholder partnerships. Farmers supply milk, and industrial processors create dairy products for national and global demands within these partnerships.

Extensive research on Sustainable Development (SD) issues in the past thirty years initially focused on understanding environmental sustainability, but it has evolved to encompass multiple dimensions beyond environmental concerns [8]. SD is inclusive development that satisfies the needs of the present without risking the needs of future generations [9]–[11]. So, SD does not imply economic well-being only but also social and environmental well-being. It underlines the holistic approach to development. In the contemporary era, economic progress often overlooks the adverse consequences on both social and environmental aspects, with deforestation for urban expansion posing a significant risk to the environment, notably contributing to issues such as global warming, climate change, desertification, soil erosion, and habitat loss, while the detrimental effects of fossil fuel and gas emissions not only harm the planet but also represent a substantial menace to humanity, aggravating numerous hazards; consequently, any initiatives taken should prioritize preserving the delicate balance of the social and ecological milieu [12]–[17].

Likewise, livestock and dairy agriculture adversely impact the terrestrial, aquatic, and atmospheric resources that are part of people's daily environment, and an escalation in demand is projected to result in meat and dairy contributing to 70% of the world's greenhouse gas emissions, despite utilizing 83% of cropland for production, in contrast to comprising just 18% of our total calorie consumption [17]–[19]. To attain food security by 2050, livestock company and industrial productivity must improve by 2.0% to 2.5% per year, as assessed by total factor productivity [1]. Eating habits have replaced conventional food habits due to gender, age, urbanization, and higher socioeconomic class, requiring the demand for meat, milk, and poultry [20].

The enhancement of animal nutrition and genetic modification of dairy cattle have led to higher milk production, yet this intensification of cattle farming can have adverse ecological consequences by depleting natural resources and elevating greenhouse gas emissions, while also presenting socioeconomic challenges, such as the potential transmission of diseases to humans from unsanitary dairy cows and conflicts between cattle and crop producers over land and water resources, which can result in both economic and personal losses [21], [22]. Rather than discontinuing the cattle industry, it is imperative to emphasize a conscientious approach that reconciles progress with the well-being of both the environment and humanity for the benefit of succeeding generations, encompassing the mitigation of greenhouse gas emissions arising from activities like high-yield grass cultivation, which poses a risk to susceptible coastal areas, and recognizing the essential role of supporting smallholder farmers in attaining this equilibrium.

The research's conceptual foundation relied on Dependency and Agency Theories, and following an exhaustive review of existing literature, the investigator identified research gaps, established objectives, and formulated research questions. This study employed a conceptual framework to examine the impacts of three independent variables (economic, social, and environmental), with engagement serving as a mediator, policy as a moderator, and sustainable dairy farming as the dependent variable. To assess these relationships, the researcher formulated seven hypotheses derived from the conceptual framework.

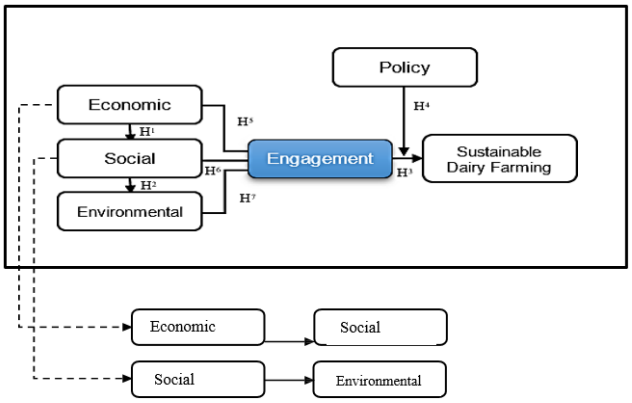

Figure 1 Conceptual Framework Quantitative

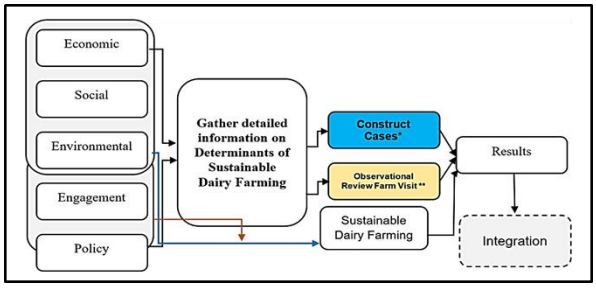

Figure 2 Conceptual Framework Qualitative

2. Objectives

This study addresses the identified issues by examining the interplay between Triple Bottom Line (TBL) determinants and sustainable dairy farming, with engagement as a mediating factor and regulatory policies governing private corporations as a moderating influence within the context of contract farming with private dairy processors. The research aims to provide solutions for sustainable dairy farming, benefiting a wide range of stakeholders including consumers, the dairy industry, the nation, and the global community, while also filling a knowledge gap in the literature specific to Bangladesh. It focuses on evaluating the impact of economic, social, and environmental factors on Sustainable Smallholder Dairy Farming (SDF), exploring the role of engagement as a mediator and policy as a moderator in the context of contract farming, and assessing the relationships between economic and social factors as well as social and environmental factors.

This research has drawn seven hypotheses considering the nature, relationship matrix, and significance of the above variables for testing the relationship. Variables with alphanumeric represent them as per Table 1.

Table 1 Research Hypotheses

	Serial No.	Code	Hypotheses
Direct Relationship	Hypothesis 1	ECO→SOC	Ceteris paribus, there is a significant relationship between Economic and Social determinants.
	Hypothesis 2	SOC→ENV	Ceteris paribus, there is a significant relationship between Social and Environmental determinants.
	Hypothesis 3	ENG→SDF	Ceteris paribus, there is a significant relationship between Engagement and Sustainable Dairy Farming.
	Hypothesis 4	POL→SDF	Ceteris paribus, there is a significant relationship between Policy and Sustainable Dairy Farming.
Mediational Relationship	Hypothesis 5	ECO→ENG→SDF	Ceteris paribus, there is a significant relationship between Economic and Sustainable Dairy Farming mediated by Engagement.
	Hypothesis 6	SOC→ENG→SDF	Ceteris paribus, there is a significant relationship between Social and Sustainable Dairy Farming mediated by Engagement.
	Hypothesis 7	ENV→ENG→SDF	Ceteris paribus, there is a significant relationship between Environmental and Sustainable Dairy Farming mediated by Engagement.

3. Methods

3.1 Research Design

Research Design creates a framework for research to get the intended result. It varies, depending on the study's nature [23]. It helps the researcher decide logically on a suitable research method appropriate for the problem, the type of data necessary, the collection method, and how convenient they are for deliveries. Research design is a preventive measure before it worsens the research design for this study is as follows:

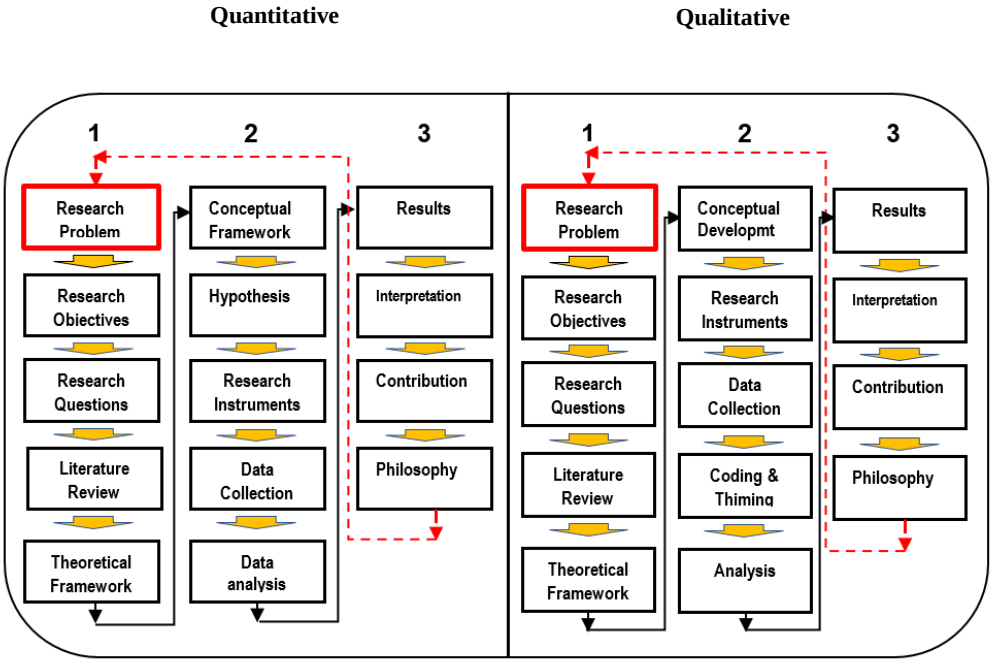

Figure 3 Research Design for the study

3.2 Research Methods

Research methods are crucial to any study. Depending on the research nature, three types of Research Design: Quantitative, Qualitative, and Mixed Methods. In this study, the researcher used Mixed methods for the convenience and nature of the population.

3.3 Mixed Method

There is a marked divergence between the methodologies of natural sciences, which predominantly employ quantitative approaches, and social sciences, particularly fields like psychology, human geography, and sociology, where qualitative methods are prevalent, with the social sciences experiencing a substantial discourse regarding research paradigms in the mid-1980s [24]. As a result, mixed methods emerged as a credible research design [25]. Even in modern times, there is still an apparent dichotomy between the two methods. Approximately 20% of studies in 2016 used a mixed-methods approach, highlighting their growing importance in recent years [24].

For the Triangulation Design: Convergence Model (a method to combine quantitative and qualitative results for evaluation [26]; Data Transformation Model (Transforming qualitative data into quantitative) [27]; Validating Quantitative Data Model (simultaneous collection of quantitative and qualitative data, which may then be integrated to provide an overall picture of a specific occurrence as part of the final discussion of the results) [28], [29]; and Multilevel Model (Multilevel modeling is a method for dealing with clustered or grouped data) [30].

Selecting a suitable method and variant depends on the researcher and the nature of the study, its intrinsic link to the research problem, and its associated methodology. The researchers in this study employed a convergent mixed-methods strategy [31].

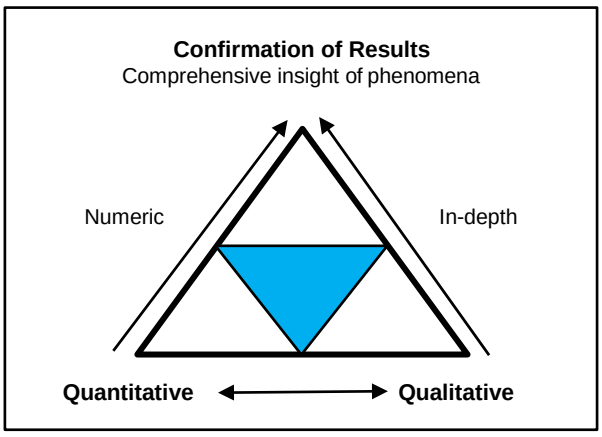

Figure 4 Triangulation relationship of mixed-method (Designed by author)

3.4 Data Collection

This study used a structured or closed-ended survey questionnaire for quantitative data. In July 2021, the researcher visited 10 smallholder dairy farms in Sirajgonj in Northern Bangladesh. The trip aimed to get a practical experience in their livelihoods, farming systems, production processes, milk supply chains, and sustainability. Before designing the questionnaire, the following key points were considered: (a) the research problem, (b) the objective, (c) the most important questions to be answered, (d) the types of people and institutions in the target population, (e) the geographic location, and, finally, (f) the time frame and costs of the research. Upon designing the questionnaire, the researcher forwarded the same to two leading academics who are highly experienced in research and a senior executive of Pran Dairy Limited, a leading professional in the dairy business [32]. After carefully reviewing all sampling options, the researcher used simple random sampling (Disproportionate technique). It is because of the nature of the population (smallholder farmers) and disproportionate characteristics, i.e., family composition, education, number of cattle, herd size, cowsheds, and ownership of land. the target population is 510 registered with PDL for ten years and more and successfully run their farming. The sample size is drawn against the target population following Krejcie and Morgan's Table (1970) [33].

The final questionnaire had two parts: the first was about the respondent's background and farm-related information, and the second was about all the variables. Demography was related to age, gender, marital status, and education. Information related to the farm includes experience, number of cattle, number of milking cows, length of the contractual relationship with PDL, yearly gross income, and spouse involvement in the farm. All these background questions are related to the objective of the study. The questionnaire of this study used the most popular 5-point Likert Scale [34], with 1 referring to strongly disagree, 2 disagree, 3 neutral, 4 agree, and 5 strongly agree.

Questions about the relationship between variables are IVs, mediators, and moderators on DV. Economic, social, and environmental factors are independent variables (IVs). Sustainable Dairy Farming (SDF) is the DV with Engagement, and policy is the associated mediator and moderator. Economics consists of 5 questions followed by 7 in social and 7 in the environment, mediator 5 and moderator 5, and DV 5. The study also looked at the direct link between economic-social and social-environmental engagement, SDF, and policy and SDF.

For the qualitative data collection, This study used purposive sampling [35] for 10, considering the time and resource constraints. 5 senior executives (Key Informants) from PRAN Dairy were also interviewed. The researcher also selected 10 contract and 10 non-contract farmers for observational review and comparative study

through farm visits. The purpose was to compare the conditions of farmers in two different categories, develop observational opinions, and compare them. The basis of comparison was their farms' economic, social, and environmental conditions and their impact on sustainable dairy farming.

3.5 Data Analysis

Data analysis used two different statistical software. The Statistical Package for Social Science (SPSS-26) [36] was used only for the demographic profile and descriptive statistics of respondents and farming information, followed by Smart PLS version 3.2.8 [37] for Assessment Measurement Model and the Structural Equation Model (SEM) technique for the quantitative part. Most exploratory researchers use PLS-SEM [38]. This study used it for path analysis, second-order factor analysis, confirmatory factor analysis, regression, correlation, and covariance models [39]. PLS-SEM is the best method for multivariate analysis in social science studies, such as the current study [38].

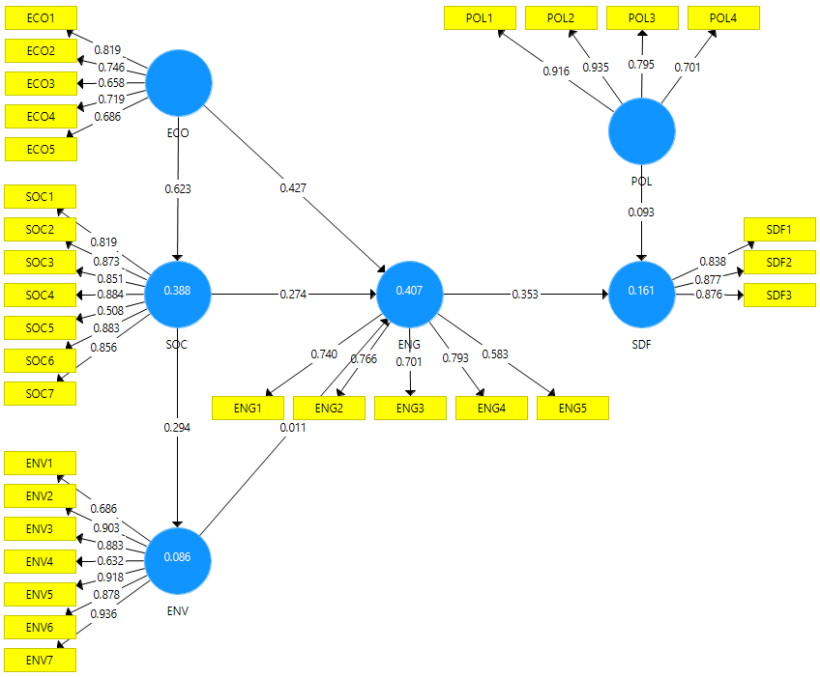

Figure 5 Conceptual Model Using SmartPLS

4. Results

4.1 Demographic Profile of Respondents

The overview of the demographic profile of the respondents is as follows,

Table 3 Demographic Profile of Respondents

Demographics	*Categories*	*Frequency n=226*	*Valid (%)*
Gender	Male	214	94.7
	Female	12	5.3
Age (years)	21-30	12	5.3
	31-40	74	32.7
	41-50	87	38.5
	51 and above	53	23.5

Marital status	Unmarried Married Divorced	9 215 2	4 95.1 0.9
Education level	No Education Primary Secondary College/Diploma University	35 133 37 16 5	15.5 58.8 16.4 7.1 2.2
Experience	10-14 15-19 20-24 25-30 31 and above	171 38 5 7 5	75.7 16.8 2.2 3.1 2.2
Farm size	Small Medium Large	83 121 22	36.7 53.5 9.7
Number of cows	1-5 6-10 11-15 16-20 21 and above	76 110 25 14 1	33.6 48.7 11.1 6.2 0.4
Types of cows	Local Hybrid Both	10 177 39	4.4 78.3 17.3
Breeding type	Friesian Cross Jersey Cross Indigenous Others	156 11 9 50	69.0 4.9 4.0 22.1
Breeding process	Natural Artificial Insemination	9 217	4.0 96.0
Total milk production Per day	Less than 20 Litre 21-40 41-60 61-80 81 and above	72 90 30 21 13	31.9 39.8 13.3 9.3 5.8
Work contribution	Husband only Husband and Children	3 16	1.3 7.1
	Wife only Wife and Children Other	70 121 16	31.0 53.5 7.1
Source of Income	Dairy Only Dairy and Agriculture- Farming Dairy and Others	15 152 59	6.6 67.3 26.0
Gross income per year from dairy	Less than 500,000	139	61.5
	600,000-10,00,000	60	26.5
	11,00,000-15,00,000	20	8.8

	16,00,000-20,00,000	5	2.2
	21,00,000 and above	2	0.9
Treatment	Regular Seldom	204 21	90.3 9.3
	Rare	1	0.4
	Never	0	0
Immunization	Regular	194	85.8
	Irregular	25	11.1
	Never	7	3.1
Types of Feed	Processed	26	11.5
	Non-processed	17	7.5
	Both	183	80.9
Distance from farm to Collection Center	Less than 1 km	105	46.5
	2-5 km	105	46.5
	6-9 km	13	5.8
	10 km and above	3	1.3

4.2 Internal consistency

Cronbach alpha and composite reliability are the most commonly used measurements for internal consistency. The values in PLS-SEM are organized based on the individual reliability of their indicators [40]. The values range from 0 to 1, with a higher value indicating greater reliability. In exploratory studies, composite reliability/Cronbach alpha values between 0.60 and 0.70 are acceptable, whereas, in more advanced stages, the value must be greater than 0.70 [40]. The outcomes of these two tests can indicate signs of internal consistency. The results of Cronbach's alpha and composite reliability achieved in this study, as projected in Table 4, show that the minimum value reported for Cronbach's alpha was 0.759, while the other variables exceeded that. On the other hand, all composite reliability values were more significant than 0.70. Based on these findings, all variables are acceptable internal consistency dependability.

Table 4 Internal Consistency Measures

Variables	***Composite Reliability (CR > 0.7)***	***Cronbach's Alpha (CA > 0.60)***
ECO	0.849	0.780
SOC	0.934*	0.913
ENV	0.943*	0.928
ENG	0.842	0.767
POL	0.853	0.791
SDF	0.799	0.759

*Hair and his associates stated CR > 0.90 or 0.95 is acceptable

4.3 Convergent Validity

Convergent Validity (CV) assessment is required to evaluate formative or reflective measurement models in PLS-SEM. CV refers to how closely a measure relates to other measures of the same phenomenon [41], [42]. Convergent validity, which verifies if a variable is accurately measured by its constituent items, was assessed in this study using the Average Variance Extracted (AVE) method recommended by Waddock and Graves (1997), and the research demonstrated acceptable convergent validity with a final AVE value exceeding the 0.5 threshold after item elimination [43].

Table 5 Average Variance Extracted (AVE) Values

Variables	***Code***	***Average Variance Extracted (AVE)*** *≥0.50 Acceptable*
Economic	ECO	0.530
Social	SOC	0.673
Environmental	ENV	0.708
Engagement	ENG	0.519
Policy	POL	0.709
Sustainable Dairy Farming	SDF	0.746

4.4 Path Coefficients

Path coefficients are standardized forms of linear regression weights that can be used in the structural equation modeling approach to investigate the possible causal link between statistical variables. The ordinary regression coefficient is standardized by multiplying it by the standard deviations of the corresponding explanatory variable; these can then be compared to assess the relative effects of the variables within the fitted regression model. The concept of standardization can be applied to partial regression coefficients.

In this study, the structural model was assessed by using path coefficients. Hair Jr et al. (2021) [40] state that the coefficient is significant if the critical value is less than the empirically measured statistical t-value. This study used a t-value of 0.95 at 0.05 significance. PLS-SEM uses bootstrapping to measure the significance of estimated path coefficients [44].Coefficients are between -1 and +1, according to the authors. Path coefficients near -1 indicate a weak relationship, while those near +1 indicate a strong one.

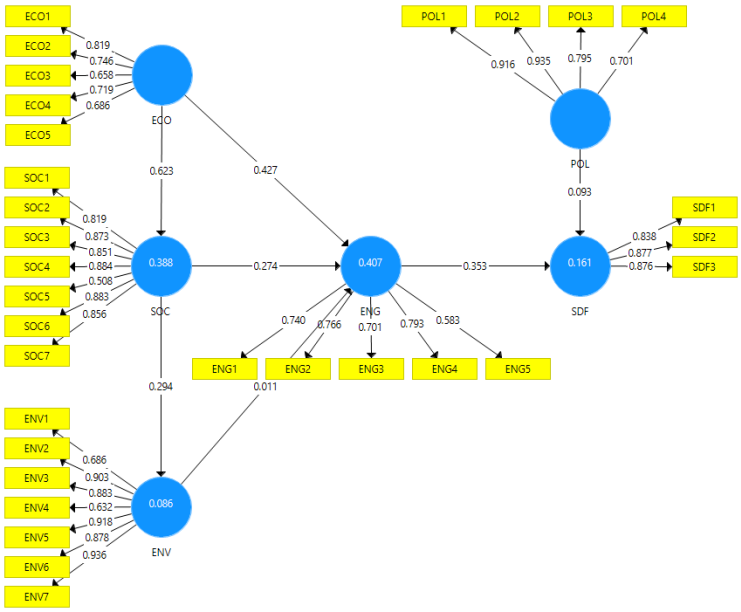

Figure 6 Path Coefficient Details

4.5 Hypotheses Testing (Quantitative)

All hypotheses were tested against the path coefficients shown in Table 6.

Table 6 Path Coefficients

Variables	Path Coefficient (PC)	Sample Mean (M)	Standard Deviation (SD)	T Statistics (T) t-value>1.96 (two-tailed)	P Values (P) P value <0.05
ECO→ENG	0.427	0.429	0.107	3.990	0.000
ECO→SOC	0.623	0.631	0.056	11.080	0.000
ENG→SDF	0.353	0.368	0.059	5.971	0.000
ENV→ENG	0.010	0.014	0.054	0.195	0.845
POL→SDF	0.092	0.096	0.047	1.943	0.053
SOC→ENG	0.274	0.274	0.087	3.131	0.002
SOC→ENV	0.294	0.297	0.093	3.148	0.002

H1 There is a significant relationship between Economic and Social determinants.

Table 6 shows the path coefficient between Economic and Social determinants is 0.623. The t-value shows 11.080, considerably higher than the threshold of 1.96 (significant at 11.080> 1.96). Similarly, the p-value indicates 0.000, smaller than the 0.05 threshold (significant as 0.000 < 0.05). H1 is acceptable means there is a significant relationship between Economic and Social determinants.

H2 There is a significant relationship between Social and Environment.

Table 6 shows the path coefficient between Social and Environmental determinants is 0.294. The t-value shows 3.148, higher than the threshold of 1.96 (significant at 3.148> 1.96). Similarly, the p-value indicates 0.002, smaller than the 0.05 threshold (significant as 0.002 < 0.05). H2 is acceptable. It means there is a significant relationship between Social and Environment determinants.

H3 There is a significant relationship between Engagement and Sustainable Dairy Farming.

Table 6 indicates the path coefficient between Engagement and Sustainable Dairy Farming is 0.353. The t-value illustrates 5.971, which is higher than the threshold of 1.96 (significant at 5.971> 1.96). The p-value of 0.000 is smaller than the 0.05 threshold (significant as 0.000 < 0.05). H3 is acceptable. It means a significant relationship exists between Engagement and Sustainable Dairy Farming.

H4 There is a significant relationship between Policy and Sustainable Dairy Farming.

Table 6 shows the path coefficient between Policy and Sustainable Dairy Farming is 0.092. The t-value illustrates 1.943, slightly smaller than the threshold of 1.96 (insignificant at 1.943< 1.96). The p-value depicts 0.053, somewhat more than the 0.05 threshold (insignificant as 0.053> 0.05). H4 is not acceptable. It means there is an insignificant relationship between Policy and Sustainable Dairy Farming.

Table 7 Mediation Analysis

Variables	Total Effect	t Statistics	p Value (Significance)	Mediational Effect	Variables	t Statistics >1.96 (Two Tailed)	p Value (Significance) <0.05
ECO→SDF	0.212	4.521	0.000	ECO→ENG→SDF	0.151	2.941	0.003
SOC→SDF	0.098	2.738	0.006	SOC→ENG→SDF	0.097	2.633	0.009
ENV→SDF	0.004	0.180	0.857	ENV→ENG→SDF	0.004	0.186	0.852

H5 There is a significant relationship between Economic and Sustainable Dairy Farming mediated by Engagement.

As per Table 7 the path coefficient between Economic and Sustainable Dairy Farming through the mediation of Engagement (ECO→ENG→SDF) is 0.003 (p-value), which is less than the 0.05 threshold (significant). Similarly, the t value is 2.941, greater than the 1.96 thresholds. H5 is acceptable means there is a significant relationship between Economic and Sustainable Dairy Farming mediated by Engagement.

H6 There is a significant relationship between Social and Sustainable Dairy Farming mediated by Engagement.

Table 7 revealed that the path coefficient between Social and Sustainable Dairy Farming mediated by Engagement (SOC→ENG→SDF) is 0.009 (P-value), which is less than the 0.05 threshold (significant). On the other hand, the t value is 2.633, which is greater than the 1.96 threshold (significant). H6 means there is a significant relationship between Social and Sustainable Dairy Farming mediated by Engagement.

H7 There is a significant relationship between Environmental and Sustainable Dairy Farming mediated by Engagement.

Table 7 shows the path coefficient between Environmental and Sustainable Dairy Farming mediated by Engagement (ENV→ENG→SDF) is 0.852 (P-value), higher than the threshold of 0.05 (insignificant). As opposed to this, the t value is 0.186, smaller than the 1.96 threshold (insignificant). H7 is not acceptable. It means there is an insignificant relationship between Environmental and Sustainable Dairy Farming mediated by Engagement.

Table 8 Hypotheses testing summary

No.		*Hypotheses*	*Result*
H^1	Direct	ECO→SOC	Significant
H^2		SOC→ENV	Significant
H^3		ENG→SDF	Significant
H^4		POL→SDF	**Insignificant**
H^5	Indirect	ECO→ENG→SDF	Significant
H^6		SOC→ENG→SDF	Significant
H^7		ENV→ENG→SDF*	**Insignificant**

Note: * H^7 became significant in qualitative findings

Table 8 Comparison of Quantitative and Qualitative Results

Quantitative				**Qualitative**		**Remarks**
Hypotheses			**Result**	**Cases/Interviews Determinants**	**Observational Indicators**	
H 1	DIRECT	ECO→SOC	Significant	10 Cases (Farmers) 5 Interviews (company executives and key informants)	Higher-income changes farmers' livelihoods, i.e., food, nutrition, family expenses, children's education, medical treatment, entertainment, vacation, women's empowerment, social status, and community	Significant

					work	
H²	DIRECT	ECO→SOC	Significant	10 Cases (Farmers) 5 Interviews (company executives and key informants)	Farmers have become increasingly environmentally conscious as a result of social development. Farmers are aware of the environmental consequences.	Significant
					Cattle well-being shows farmers' environmental awareness. Farmers' economic constraints may limit ecological conservation—environmentally friendly shed layout, cleaning, waste management, ventilation, temperature, and water use indicate good environmental practices.	
H 3	DIRECT	ENG→SDF	Significant	10 Cases (Farmers) 5 Interviews (company executives and key informants)	Farmers' economic, social, and environmental growth shows they are fully involved with PDL, leading to improved breeding, high-yielding cows, more milk, and more cash. These are SDF signs.	Significant

H 4	DIRECT	POL→SDF	Insignificant	10 Cases 5 Interviews (company executives)	According to the interview, the local government and allied agencies failed to help smallholder farmers by implementing the law, controlling major milk processors, providing loans, clinical support, better breeding, subsidized feed, AI support, credit, and vaccination. So, the insignificant relationship between POL→SDF is justified.	Insignificant
H 5		ECO→ENG → SDF	Significant	10 Cases (Farmers) 5 Interviews (company executives and key informants)	Profitability depends on better breeds, high-yield cattle, safe AI, nutritious feed, layout, animal welfare, hygiene milking process, preservation, and transportation. These require knowledge and skills. Active engagement with dairy processors under contract farming can facilitate these conditions. Economic determinants can enhance SDF mediated by engagement visible among the farmers during the interview. So, both quantitative and	Significant
					qualitative findings are similar.	

H 6	INDIRECT	SOC→ENG → SDF	Significant	10 Cases (Farmers) 5 Interviews (company executives and key informants)	Better livelihood enhances better farm management, including input-process-output. These are related to SDF, which can be improved by engagement with the industrial processor.	Significant
H 7	INDIRECT	ENV→ENG → SDF	Insignificant	10 Cases (Farmers) 5 Interviews (company executives and key informants)	Qualitative studies favor ENV→ENG→SDF. Insufficient data may make environmental assessments incomplete. In thorough interviews, farmers were better involved with the processor to manage cow waste, clean animal discharge, organic fertilizer, and biogas. These are eco-friendly.	Significant

The comparative assessment of factors influencing the sustainability of dairy farming (SDF) underscores the significance of economic development (ECO), social development (SOC), and engagement with the dairy industry (ENG) as pivotal determinants of SDF, while policy support (POL) was observed to lack a significant impact on SDF.

ECO→SDF

Economic development directly and positively contributes to SDF, as farmers with higher incomes are more inclined to invest in sustainable practices, encompassing advancements in breeding, nutrition, and animal welfare. Economic development concurrently spurs an augmented demand for dairy products, motivating farmers to embrace sustainable farming practices.

SOC→SDF

Social development also directly and positively influences SDF, as socially developed farmers exhibit greater awareness of sustainability's importance and motivation to adopt sustainable practices. Social development affords increased access to educational resources and information, facilitating farmers' knowledge acquisition in sustainable farming techniques.

ENG→SDF

Directly, engagement with the dairy industry has a positive impact on SDF, as dairy companies offer resources and support for the adoption of sustainable practices, including access to improved livestock breeds, nutrition, and animal welfare training. Furthermore, dairy companies assist farmers in marketing their sustainably produced milk and dairy products.

ECO→ENG→SDF

Economic development indirectly fosters SDF through its association with engagement with the dairy industry. Economically successful farmers are more likely to engage with dairy companies, which, in turn, are incentivized to invest in sustainable practices in response to the demand for sustainably produced dairy products

SOC→ENG→SDF

Similarly, social development indirectly supports SDF through its connection with engagement with the dairy industry, as socially developed farmers are more likely to collaborate with dairy companies, which are further motivated to invest in sustainable practices when they recognize customer concerns about sustainability which is **ENV→ENG→SDF**

Although environmental awareness was posited to have an indirect positive influence on SDF through engagement with the dairy industry, this relationship did not attain statistical significance in the study. This may be attributed to the relatively nascent status of environmental awareness in many developing nations, with dairy companies still in the process of formulating and implementing sustainable practices.

5. Discussion

Population growth is exponential. Food, nutrition, and dairy product demand also increased. Due to worldwide dietary patterns, dairy demand has skyrocketed. Thus, sustainable dairy farming is necessary to maintain the supply chain for consumers and industrial dairy processors. Like other developing nations, smallholder dairy farmers in Bangladesh produce 70%-80% of milk. However, they live below subsistence and struggle to farm. It undermines sustainable production by affecting output. Sustainability depends on economic, social, and environmental factors. Poor farmers struggle to value these variables. Therefore, stakeholders must assist them.

This study aimed to analyze the influence of three determinants (TBL) on SDF with a mediation and moderation effect between the independent and dependent variables. The research also assesses the vertical relationship between economic-social and social-environmental factors.

Considering the outcome of this research, the following figure 7 can be a Role Model in sustainable dairy farming for smallholders in Bangladesh and other emerging countries.

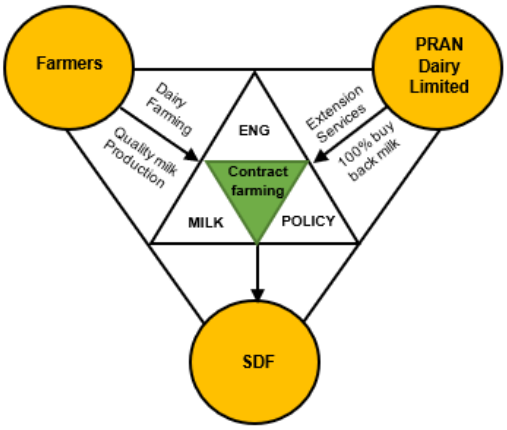

Figure 7 Model of Smallholder Sustainable Dairy Farming ENG = Engagement SDF = Sustainable Dairy Farming

The findings and logical interpretation of other pertinent data led the researcher to the following conclusions:

- Farmers' economic conditions affect their social livelihoods. Farmers with higher output have better houses, clean water, nutrition, kids' education, health, and social recognition. This concept was substantiated by quantitative and qualitative analyses (H1).

- Quantitative and qualitative methods revealed a significant link between social and environmental factors (H2). Farmers were increasingly conscious of the environmental impact of dairy farming as socially developed. They recognize that animal waste has a direct effect on the environment. Socially developed farmers handle ecological issues more effectively.
- SDF is directly associated with engagement (mediator) in this study (H3). The mediator incentivized farmers by providing training in farm management, animal welfare, AI, breeding, high-yield milk, and supply chain. Quantitative and qualitative results support this notion.
- There was an insignificant relationship between policy and SDF (H4). It is due to the absence of active government participation and policy for protecting smallholder dairy farmers. Both quantitative and qualitative methods found similar results. Subject farmers consistently reported receiving little or no local or federal government aid (loan, clinical, regulatory). Qualitative analysis showed similar results.

This study assessed the role of engagement in mediating the relationship between independent variables Economic (ECO), Social (SOC), Environment (ENV), and dependent variables Sustainable Dairy Farming (SDF) (using H5, H6, & H7). In this study, the effect of the mediating variable is validated based on the indirect effect between the dependent and independent variables only.

- The economic determinant is significantly related to SDF supplemented by the mediator engagement. Both quantitative and qualitative results support this hypothesis (H5). Engagement boosted all parameters of profitable production and enhanced revenue.
- Similarly, social factor is strongly related to SDF when mediated by engagement. Practical attachment with the private processor helped farmers develop their and animal livelihoods. It directly helped sustainability in this study. Quantitative and qualitative outcomes are comparable (H6).
- Even with the mediator, the environmental factor is insignificantly related to SDF (H7). A lack of sufficient information could be a reason for quantitative analysis. However, qualitative data support the relationship.

Qualitative findings are fully aligned with the quantitative outcomes except for policy. The result of the policy and SDF was expected as government participation was minimal. This is a very significant finding for policymakers.

The recommendations for policy implications can be categorized into theoretical and practical aspects. The theoretical recommendations underscore the positive contributions made by incorporating engagement as a mediator and policy as a moderator in the relationship between determinants and sustainable dairy farming (TBL). Additionally, the establishment of vertical connections between independent variables, such as economic and social factors, and social and environmental relationships, strengthens the understanding of the TBL framework. The development of a composite model derived from this research is highlighted as a valuable addition to the realm of sustainable dairy farming, serving to benefit policymakers and the dairy industry. On a practical note, it is imperative for the government to oversee contract farming to ensure its success in promoting Sustainable Dairy Farming (SDF), with specific attention to food security and the dairy industry's supply chain. Effective policy formulation and administration are stressed, particularly considering that the majority of farmers in the research region are engaged in contract farming under a major dairy processor. Clear policies and regulations need to be established by the Department of Livestock Services (DLS) to monitor and regulate the activities of dairy companies. Given the environmental impact of dairy farming, accountability for non-compliance by contract farmers should be held by the dairy processors. Furthermore, the DLS should incorporate an arbitration wing to assist farmers in resolving disputes related to milk pricing, quality, weight, and payment. Independent farmers, facing significant economic, social, and environmental challenges without support from dairy companies, should receive assistance from the local DLS through hands-on training, workshops, online clinical advisory services, vaccination programs, artificial insemination support, medical care, and designated veterinary professionals. The Ministry of Agriculture should actively encourage villagers, especially young individuals and the unemployed, to engage in dairy farming and inspire existing farmers to plan for succession in light of the aging population. Recommendations for private dairy processors emphasize the necessity of clear policies regarding contract farming, including selection criteria, extension services, milk pricing mechanisms, and procedures for dispute

resolution and arbitration. The agreement between farmers and companies should explicitly outline their respective duties and responsibilities, with farmers receiving a copy of the contract. Audit committees should be established by the companies to oversee collection center activities, with representation from both the company and the farmers to ensure mutual accountability and fair practices. It is also recommended that collection centers be organized, spacious, and efficient in their milk collection processes.

Based on the constraints and insights of the current study, future research should broaden its geographic scope, examine sub-factors within the economic, social, and environmental dimensions of Triple Bottom Line analysis, consider both direct and indirect relationships, include non-contractual farmers, explore the impact of government policies, and assess the applicability of findings to other regions within the country for more representative conclusions.

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