ADDIS ABABA UNIVERSITY

COLLEGE OF BUSINESS AND ECONOMICS

SCHOOL OF COMMERCE

SCALABLE BUSINESS MODELS FOR SOLAR MILK COOLING IN RURAL ETHIOPIA: - A CASE STUDY OF DENKAKA COOPERATIVE TO SUPPORT ADOPTION AND SUSTAINABILITY

A Research Project Submitted to Office of Graduate Studies of Addis Ababa University School of Commerce in Partial fulfillment of the requirement for Degree of master's in business leadership

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POST GRADUATE PROGRAM

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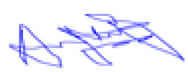
Asmamaw Argeta(PhD)		**08/8/2025**
External Examiner	**Signature**	**Date**

DECLARATION

I Lijalem Eshetu, do hereby declare that this project is my original work and that it has not been submitted partially; or in full, by any other person for an award of a degree in any other university/institution and I conducted under the guidance of Dr. Bahren Asrate and all the sources of materials used in the manuscript have been duly acknowledged.

Declared by:

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Name	Signature	Date

STATEMENT OF CERTIFICATION

This is to certify that this study paper titled **"Scalable Business Models for Solar Milk Cooling in Rural Ethiopia:-A Case Study of Denkaka Cooperative to Support Adoption and Sustainability "** undertaken by **Lijalem Eshetu** for the partial fulfillment for degree of Masters in Business Leadership (MBL) from Addis Ababa University school of post graduate program is an original work and fit for partial fulfillment for degree of Masters in Business Leadership.

Research Advisor	Signature	Date

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ABSTRACT

Post-harvest milk spoilage remains a significant barrier to dairy sector growth in Ethiopia, where smallholder farmers lack access to reliable cold chain infrastructure. Solar Milk Cooling (SMC) technologies offer a renewable energy-based solution to this challenge, yet their adoption and scalability remain limited. This research investigates how a sustainable and scalable business model for SMC can be developed and implemented within Ethiopia's unique socio-economic and geographic context. Using a mixed-methods approach, the study draws on surveys (n=178) and qualitative interviews across smallholder farmers, cooperative members, and institutional stakeholders. The findings highlight widespread milk spoilage (10–30% loss), strong interest in SMC, and key barriers such as high capital cost, limited financing, and technical support gaps. Leadership within cooperatives and stakeholder collaboration emerged as critical enablers. The study proposes a cooperative-based, service-oriented business model grounded in the Business Model Canvas framework, supported by tailored financing, stakeholder engagement, and capacity building. The results offer strategic recommendations for policy makers, development partners, cooperatives, and the private sector. This research contributes to the growing body of knowledge on renewable energy for agriculture and provides a practical roadmap for scaling SMC in Ethiopia_by aligning technology, cooperative governance, and financing to the country's rural dairy ecosystem.

Key Words: Solar Milk Cooling (SMC), Business Model Canvas (BMC), Smallholder Farmers,

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ACRONYMS

AAU	Addis Ababa University
BMC	Business Model Canvas
CRGE	Climate Resilient Green Economy
CSR	Corporate Social Responsibility
FAO	Food and Agriculture Organization
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOGLA	Global Off-Grid Lighting Association
IoT.	Internet of Things
KPI	Key Performance Indicator
MFI	Microfinance Institution
MoA	Ministry of Agriculture
NGO	Non-Governmental Organization
PAYG	Pay-As-You-Go
PPP	Public-Private Partnership
ROI	Return on Investment
SBM	Sustainable Business Model
SEFFA	Sustainable Energy for Smallholder Farmers in Africa
SMC	Solar Milk Cooling
SPSS	Statistical Package for the Social Sciences
TLBMC	Triple Layered Business Model Canvas

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Business models are strategic frameworks describing how organizations create, deliver and capture value. The Business Model Canvas (BMC) is a popular tool that breaks a business model into nine blocks (value proposition, customers, channels, revenues, etc.) to systematically design innovations (Osterwalder & Pigneur, 2010). Building on this, sustainable business models (SBMs) explicitly integrate social and environmental outcomes alongside economic viability (Bocken et al., 2014). The Triple-Layered BMC (TLBMC) extends the BMC to include an environmental and a social layer, making sustainability concerns explicit in planning (Joyce & Paquin, 2016). This study adopts these frameworks to ensure that solar milk cooling models are economically sound, socially inclusive, and environmentally responsible. Agricultural value chains in Sub-Saharan Africa often suffer from weak infrastructure: for example, an erratic grid in India alone causes an estimated 2% of national milk production to spoil (WWF India, 2023). Ethiopia is similar: smallholder farmers produce over 95% of the country's milk, yet frequent power outages and lack of refrigeration mean that a large share of output perishes before it reaches markets (Ayele & Shiferaw, 2020). Development programs such as GIZ's SEFFA and SNV's "Milking the Sun" have started to introduce solar-powered milk coolers in Ethiopia and neighboring countries, recognizing that clean energy can break cold-chain bottlenecks. In the Denkaka Cooperative (Serdo, Bishoftu), a solar chiller was co-owned by farmers to preserve evening milk. By charging a small storage fee per liter, the cooperative enabled members to double their daily marketable milk and increase incomes by ~25–30% (SNV, 2021). These results echo successes elsewhere: for instance, the Swiss NGO Promethean Power's thermal storage chillers in India now reliably chill milk for multiple villages, reducing spoilage and ensuring farmers get paid on time (Greentech Media, 2022). Despite such pilots, a coherent strategy for scaling SMC in Ethiopia is missing. Key bottlenecks include financing (farmers have low purchasing power and limited credit), institutional capacity (cooperatives need technical skills to maintain chillers), and leadership/coordination (driving community buy-in). Moreover, existing SMC projects often rely on external subsidies and lack plans for long-term sustainability. Research suggests that to achieve scale, an SMC initiative must align the technology with a viable business model that covers costs (or secures financing), rewards all stakeholders, and adapts to local culture and leadership structures (Bocken et al., 2014; Joyce & Paquin, 2016). In Ethiopia's context, leveraging local leadership – e.g. cooperative chairpersons and extension agents – may be crucial for user training and trust-building. Ultimately, a sustainable SMC business model should not only prevent milk loss, but also create economic value for farmers, investors, and the community, as well as social benefits (improved livelihoods) and environmental benefits (clean energy use).

1.2 Statement of the Problem

In developing country dairy sectors, post-harvest losses are very high (Alliance for Rural Electrification, 2021). In Ethiopia, lack of reliable cooling is estimated to waste a large fraction of milk production (World Bank, 2024). This waste undermines the livelihoods of smallholder farmers and the potential of the rural economy. Solar milk cooling (SMC) can technically address the spoilage problem, but in Ethiopia its adoption is still in early, fragmented stages. Pilot systems have shown success (e.g., the Denkaka cooperative case) (SNV, 2021), but such isolated projects rarely move beyond the pilot phase due to unclear follow-on planning. No established business model exists to commercialize or scale SMC under Ethiopian conditions. Key issues remain unanswered: Who will invest or lend for these systems? How can costs be recouped in communities with limited cash flow? How should the responsibilities be divided between cooperatives, farmers, and service providers? Without a clear model, each new SMC initiative tends to be a one-off with donor support. This gap has practical consequences: innovations fail to spread, dairy cooperatives miss opportunities to add value, and farmers continue to suffer avoidable losses (FAO, 2023). The central problem then is designing a scalable, sustainable business approach for SMC that matches Ethiopia's socio-economic context. It must integrate local leadership and stakeholder engagement so that cooperatives and farmers actually take ownership, and ensure economic feasibility so that the systems can be maintained over time. In short, the study seeks to solve: How can solar milk cooling be implemented and scaled in rural Ethiopia through a business model that is both self-sustaining and socially inclusive? Addressing this requires examining current milk handling practices (and their shortcomings), identifying barriers to SMC uptake, understanding the role of leadership and collaboration, and then assembling a viable model that ties these elements together.

1.3 Research Questions

The study is guided by the following research questions:

1. What milk handling practices contribute to spoilage, and what impact can solar milk cooling have at the farm level?
2. What are the major challenges and supporting conditions for SMC adoption in rural Ethiopian communities?
3. In what ways do leadership practices and stakeholder collaboration influence the scaling of SMC systems?
4. What business model design best fits the scaling of SMC systems in Ethiopia's dairy sector?

Each question probes a core aspect of the problem – from technical losses on farms to socio-economic enablers – and collectively they inform the integrated framework for an SMC business model.

1.4 Research Objectives

The general objective of the study is to design a scalable and sustainable business model for solar milk cooling systems that integrates local leadership, economic feasibility, and strategic implementation to reduce milk loss and support rural dairy transformation in Ethiopia.

Specific Objectives:

1. To assess milk handling practices and spoilage issues at the smallholder level;
2. To identify barriers and enabling factors for SMC adoption in rural cooperatives;
3. To examine the role of leadership and stakeholder engagement in SMC scaling;
4. To develop a context-specific, cooperative-based business model for SMC.

These objectives build on each other: first understanding the problem on farms, then the socio-institutional context, and finally synthesizing that knowledge into a practical model.

1.5 Significance of the Study

This research contributes both practically and academically. Practically, it offers concrete guidance for policymakers, NGOs, and dairy cooperatives on how to structure investments and operations for SMC. By highlighting the importance of leadership and local engagement, it suggests policies for cooperative governance and training. Academically, the study enriches the literature on renewable energy in agriculture by linking technology adoption to business model innovation. It extends frameworks like the Sustainable Business Model Canvas (Bocken et al., 2014) to a new application. The findings – drawn from mixed-methods field research – will provide evidence of how much spoilage is being prevented by solar chillers, and the socio-economic outcomes of cooperative-based SMC. In sum, this study serves stakeholders interested in rural development, renewable energy, and agri-business by charting a way to turn solar cooling from pilots into self-sustaining solutions in Ethiopia.

1.6 Scope of the Study

The study focuses on solar milk cooling as an intervention in the dairy value chain. Geographically, primary data collection is concentrated in Serdo Village (Denkaka Cooperative, Oromia Region) and relevant Addis Ababa institutions, where the SMC pilot has been implemented. Findings are analyzed with the broader Ethiopian dairy context in mind. The research examines technological, economic, and social dimensions of SMC, using a mixed-methods approach to capture both qualitative stakeholder insights and quantitative measures (e.g. milk quality and volumes). While centered on one cooperative case, the aim is to derive lessons generalizable to similar rural dairy settings in Ethiopia.

1.7 Limitations of the Study

The single-case focus (Denkaka Cooperative) means context-specific factors may limit generalization to all of Ethiopia's diverse regions. Reliance on interviews and surveys introduces potential bias from self-reporting by participants. To mitigate this, the study triangulates by using diverse data sources (farmer surveys, coop records, expert interviews). External factors – such as changes in dairy prices, policy shifts, or foreign exchange fluctuations – could also influence the findings during the research period. The study acknowledges these constraints but emphasizes that the proposed business model will be designed with adaptability in mind, allowing for adjustments as conditions change.

1.8 Organization of the Study

The thesis is organized as follows: Chapter One (this chapter) presents the introduction, including background, problem statement, research questions and objectives, significance, scope, and limitations. Chapter Two provides a comprehensive literature review covering definitions, theoretical frameworks (e.g. BMC, SBM, TLBMC), global and Ethiopian empirical cases of SMC, and identified gaps. It concludes with the conceptual framework guiding this research. Chapter Three outlines the methodology used for data collection and analysis. Chapter Four presents the findings from the case study (milk handling practices, barriers, leadership roles, etc.) and proposes the cooperative-based business model. Finally, Chapter Five offers conclusions and recommendations, discussing policy implications, future research, and strategies for scaling up solar milk cooling in Ethiopia.

1.9 Definition of Key Terms

Solar Milk Cooling (SMC): A sustainable milk preservation technology that uses solar energy to power cooling equipment. SMC systems enable dairy producers in off-grid areas to chill milk (typically to 4°C or lower), thereby improving milk quality, reducing post-harvest losses, and expanding market access (Straubel, 2019).

Business Model: A holistic plan for creating, delivering, and capturing value. It defines a firm's value propositions, customer segments, revenue streams, and cost structures (Osterwalder & Pigneur, 2010).

Business Model Canvas (BMC): A strategic tool defining nine building blocks of a business (value proposition, customer segments, channels, customer relationships, revenue streams, key activities, key resources, key partnerships, cost structure). The BMC is used to systematically analyze and design the SMC business model components (Osterwalder & Pigneur, 2010).

Sustainable Business Model (SBM): A business model approach that explicitly integrates social and environmental goals with economic objectives. SBMs use a “triple bottom line” perspective (people, planet, profit) and consider all stakeholders’ needs (Bocken et al., 2014).

Triple-Layered Business Model Canvas (TLBMC): An extension of the BMC that adds environmental and social layers to the traditional economic canvas. The TLBMC helps to visualize how a business (like an SMC service) generates multiple types of value (Joyce & Paquin, 2016).

Cooperative: A democratically-managed business owned by a group of members (farmers in this case), who collectively share costs, resources, and benefits. A dairy cooperative pools member milk and often provides services (like cooling) to them. Cooperative-based models leverage the group structure for joint investment and equitable profit distribution.

Stakeholder Engagement: The process of involving all parties with an interest in the project (farmers, coop leaders, government, NGOs) in decision-making. Effective engagement ensures that the business model reflects local knowledge and secures buy-in from those who will operate and benefit from the SMC system.

CHAPTER TWO:

REVIEW OF RELATED LITERATURE

2.1 Definitions and Concepts Related to the Topic

This section clarifies key concepts that provide a foundation for the study of scalable solar milk cooling (SMC) business models. A business model describes how an organization creates, delivers, and captures value. It is essentially a blueprint for an enterprise's operations, covering aspects such as customer value, product or service offerings, financial flows, and delivery channels (Osterwalder & Pigneur, 2010). One widely adopted tool to conceptualize this is the Business Model Canvas (BMC), which breaks down the business model into nine key elements: customer segments, value propositions, channels, customer relationships, revenue streams, key activities, key resources, key partnerships, and cost structure. This framework provides a visual and strategic overview of how a business operates and sustains itself (Osterwalder & Pigneur, 2010).

In the context of rural energy solutions such as SMC, a business model must address who pays for the cooler, how services are delivered, who maintains the equipment, and how revenues are generated and shared. To go beyond economic logic, the Sustainable Business Model (SBM) concept expands traditional business thinking to include social and environmental value creation alongside financial goals. An SBM incorporates the triple bottom line—people, planet, and profit—by embedding sustainability and inclusivity into the core of the business model (Bocken et al., 2014). For instance, in SMC systems, the SBM lens would consider not only the economic return to farmers but also environmental benefits from using solar energy instead of diesel, and social value through community empowerment.

The Triple-Layered Business Model Canvas (TLBMC), developed by Joyce and Paquin (2016), builds upon the BMC by adding two additional layers: one for social impacts and one for environmental impacts. This holistic framework encourages entrepreneurs to examine how their business models affect society (e.g. labor conditions, gender inclusion) and the environment (e.g. carbon footprint, resource efficiency). For SMC, the TLBMC enables analysis not only of financial performance but also of ecological factors such as solar panel waste management and social issues such as women's participation in cooperative leadership. As a tool, the TLBMC aligns business innovation with long-term sustainability goals.

Scalability is another crucial concept. It refers to the ability of a business model or intervention to expand in size, impact, or geographic coverage without a proportionate increase in per-unit costs (Cooley & Linn, 2014). In the case of SMC, a scalable model would be one that can be replicated across many cooperatives or rural communities using the same fundamental design, while maintaining affordability and quality. Such scalability requires not only technical feasibility and cost-effectiveness but also organizational capacity, leadership, and stakeholder coordination.

A cooperative-based model refers to a structure where the equipment and services are collectively owned or managed by a farmer cooperative. These models are particularly relevant in rural Ethiopia, where cooperative institutions serve as social and economic anchors. In such models, members contribute to operational costs through small service fees, and decision-making is community-led. While this approach can lower barriers to entry and increase buy-in, its success depends heavily on transparent governance, financial literacy, and effective leadership within the cooperative (Birchall, 2004).

2.2 Theoretical Review and Adopted Framework

This study is grounded in multiple interlinked theoretical frameworks that support the development of a sustainable and scalable business model for solar milk cooling. The foundational framework is the Business Model Canvas (BMC) developed by Osterwalder and Pigneur (2010), which provides a structured and visual representation of how a business operates. The BMC is widely used in both academic and practical business contexts to conceptualize start-ups, product strategies, and social enterprises. In rural energy projects, it serves to outline value propositions (e.g. reliable milk cooling), key partnerships (e.g. NGOs or equipment suppliers), and cost and revenue models.

Building upon this, the Sustainable Business Model (SBM) theory introduces the importance of integrating environmental and social outcomes into business planning (Bocken et al., 2014).

Unlike traditional models that focus primarily on profit, SBMs ensure that innovations like SMC systems are designed with broader societal and ecological impacts in mind. In this context, an SBM ensures that farmers benefit equitably, that environmental harm is minimized, and that the business remains viable over the long term.

To operationalize sustainability more thoroughly, this study also adopts the Triple-Layered Business Model Canvas (TLBMC) by Joyce and Paquin (2016), which extends the BMC to include an environmental layer and a social layer. This approach enables practitioners and researchers to evaluate a business model's environmental impacts (such as CO_2 savings from solar use) and social benefits (like employment or gender inclusion) alongside its financial feasibility. The TLBMC thus provides a comprehensive view that is especially relevant in development contexts.

Given the study's focus on scaling innovations, the framework also draws upon scalability theories such as the Scaling Up Management Framework by Cooley and Linn (2014). This theory emphasizes the need for innovation to be adaptable, institutionally supported, and responsive to stakeholder dynamics. According to this approach, successful scale-up requires local leadership, policy alignment, and sustainable financing—elements that are integral to the research questions in this study.

Altogether, this study adopts a hybrid framework combining the BMC, SBM, and TLBMC. This enables an evaluation of economic viability (using BMC), sustainability and stakeholder inclusivity (through SBM and TLBMC), and scalability dimensions (informed by Cooley and Linn, 2014). This comprehensive framework informs the research design, the formulation of interview guides and questionnaires, and the structure of the proposed SMC business model.

2.3 Empirical Review

Empirical studies across multiple countries have examined the application of solar milk cooling and related energy innovations in rural dairy sectors. In India, WWF-India's dairy cold chain initiative demonstrated how solar-powered milk chillers reduced diesel use and improved farmer income in Uttar Pradesh and Rajasthan (WWF India, 2022). These projects showed that renewable energy solutions could cut milk wastage in half while reducing electricity bills.

However, many of these initiatives relied on NGO or government funding, highlighting the need for sustainable business models with clear revenue and repayment structures (Singh et al., 2019).

Kenya has also made notable strides in SMC adoption. The SelfChill system, developed in partnership with German organizations, used direct current (DC) solar chillers at cooperative milk collection centers. In Tharaka Nithi County, a cooperative-run solar plant facilitated continuous chilling even during power outages and enabled higher milk volumes to be collected (ARE, 2021). Farmers paid a small percentage of their earnings to maintain the service, demonstrating financial feasibility through community ownership.

In Uganda, Heifer International's "Solar for Sustainable Income in Dairy" project outfitted collection centers with large-scale solar arrays. One such cooperative eliminated nearly $30,000 in annual diesel costs, cooled over 197,000 liters of milk monthly, and increased farmer incomes through efficiency and reduced spoilage (Heifer International, 2023). These cases demonstrate that solar cooling, when paired with strong cooperative structures and public-private partnerships, can deliver substantial benefits.

In Ethiopia, the Denkaka Cooperative pilot supported by GIZ-SEFFA introduced a 160L solar chiller. Early observations suggest increased evening milk collection and improved farmer income. However, there is limited data on long-term cost recovery, governance effectiveness, or system scalability. Other local pilots by SNV and the Ministry of Agriculture have installed solar cooling systems, but these remain fragmented and often lack sustainable financing and user training (SNV Ethiopia, 2022). These Ethiopian experiences reveal technical feasibility but point to capacity gaps in cooperative governance, pricing, and long-term sustainability.

Overall, empirical studies support the idea that SMC systems can reduce milk spoilage and increase income for rural farmers. However, success depends on appropriate delivery models—such as pay-as-you-store or cooperative-based models—that ensure affordability, operational sustainability, and stakeholder buy-in. The most promising models combine technology, finance, training, and community engagement in an integrated manner.

2.4 Gap of the Study

Despite the encouraging evidence presented in the empirical review, several gaps remain that justify this research. First, Ethiopia-specific studies on solar milk cooling business models are scarce. Most documented cases are from other countries or describe technical feasibility without detailing organizational models or economic structures. Second, the literature has yet to integrate leadership dynamics and stakeholder engagement into the scaling process. Aspects such as how cooperative leaders facilitate adoption or how NGOs and government actors coordinate to enable uptake remain underexplored. Third, there is a lack of quantitative data on unit economics, such as actual operating costs, pricing models, and payback periods under Ethiopian conditions. Fourth, gender and social equity dimensions are often overlooked. While women are active in dairy cooperatives, their role in managing or benefiting from SMC initiatives is seldom analyzed. Finally, previous studies have largely ignored the integration of theoretical frameworks like SBM and TLBMC into the evaluation of energy access models. This study aims to bridge these gaps by using a comprehensive framework and collecting both qualitative and quantitative data in the Ethiopian context.

2.5 Conceptual/Theoretical Framework

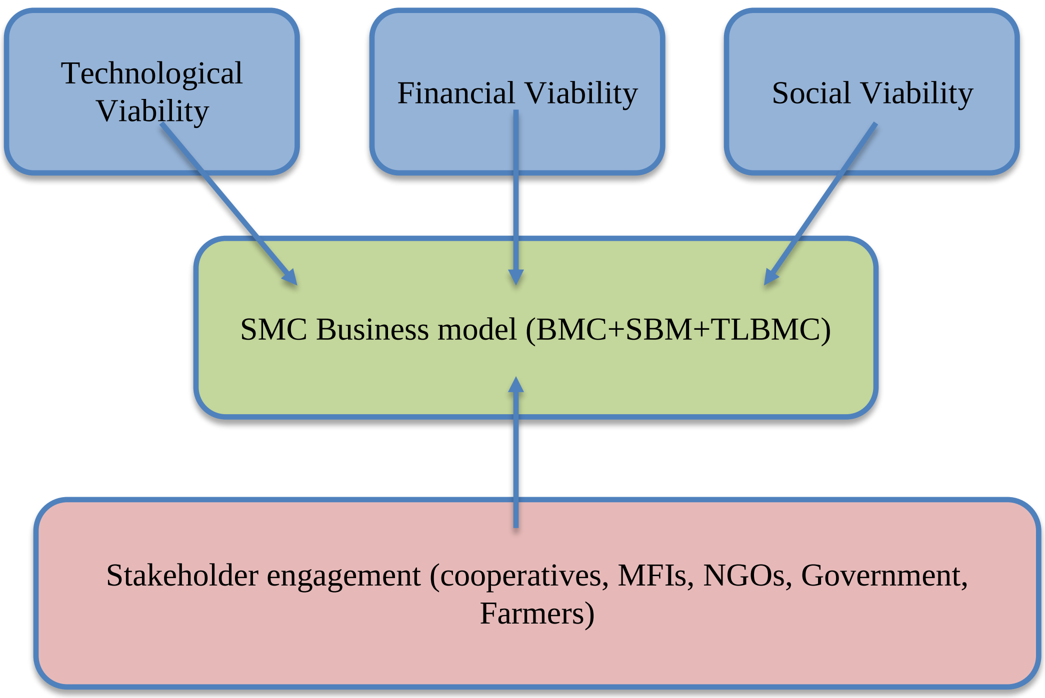
Based on the synthesis of theoretical models and empirical cases, this study proposes an integrated conceptual framework to guide the analysis of solar milk cooling adoption and scalability. The framework is centered around the Business Model Canvas (Osterwalder & Pigneur, 2010), which structures the model into core business components. These elements are then overlaid with sustainable business model principles (Bocken et al., 2014) and triple-layered perspectives (Joyce & Paquin, 2016), ensuring the inclusion of social and environmental impacts alongside economic performance.

At the heart of the framework is the value proposition of SMC: to reduce milk spoilage and increase income through decentralized, solar-powered cooling services. The framework recognizes three interrelated dimensions—technological viability, economic feasibility, and social acceptability. These dimensions are mediated by cooperative leadership, stakeholder engagement, and financing mechanisms. For example, cooperative leaders act as enablers of trust, coordination, and training, while partnerships with financial institutions and NGOs support capital acquisition and operational continuity.

The environmental layer includes solar energy use and carbon offset potential, while the social layer considers equity, community involvement, and capacity building. The economic layer includes pricing, revenue, and operational sustainability. These layers inform not only the design of the business model but also its assessment criteria in the data collection tools.

Figure 2.1 below illustrates the conceptual framework adopted in this study. This figure also informs the data analysis and discussion in Chapters Four and Five, serving as a guiding map to evaluate the business model's performance and scalability potential.

Figure 2. 1 Conceptual Framework for Solar Milk Cooling Business Model Adoption – based on BMC, SBM, and TLBMC principles



CHAPTER THREE:

RESEARCH METHODOLOGY

3.1 Description of the Study Area

The study is conducted in Serdo Village, Bishoftu, within the Oromia Region of Ethiopia. The village hosts a substantial population of smallholder dairy farmers operating in peri-urban and off-grid areas, where access to reliable electricity is limited. This makes the village an ideal case for investigating the relevance, feasibility, and scalability of solar-powered milk cooling systems. The area is also part of pilot implementation zones for renewable energy-based agricultural innovations.

3.2 Research Approach

A mixed-methods approach is adopted to gain a comprehensive understanding of the challenges and opportunities in scaling SMC business models:

- Qualitative methods form the core of the study, allowing in-depth investigation of stakeholder experiences, business model dynamics, and contextual barriers.
- Quantitative data provides complementary insights, supporting pattern identification, validating qualitative findings, and offering broader generalizability.

3.3 Research Design

The study follows a case study design with descriptive and exploratory components:

- Descriptive elements capture the current structure and functioning of existing SMC initiatives, stakeholder roles, and business models.
- Exploratory elements identify key barriers and enabling conditions for scale-up, and help formulate context-sensitive recommendations.

This study is guided by the conceptual framework presented in Figure 2.1, which integrates the Business Model Canvas (BMC), Sustainable Business Model (SBM), and stakeholder engagement principles to examine the adoption and scalability of solar milk cooling (SMC) systems. The framework informed the development of research instruments and the selection of key variables, emphasizing the interconnection between technological, economic, and social dimensions. It also shaped the research design by highlighting the role of cooperative leadership, financial viability, and institutional support in driving adoption. Both the quantitative and qualitative instruments were structured to explore these dimensions, ensuring coherence between theoretical foundations and empirical inquiry.

3.4 Population and Sampling

3.4.1 Sample Size Determination and Allocation

Using Yamane's (1967) formula, a statistically valid sample size is determined:

$n = N / (1 + N(e)^2)$

Where:

- $N = 550$ (180 cooperative members, 300 smallholder farmers, 70 experts)
- $e = 0.05$ (for 95% confidence level)

$n = 550 / (1 + 550(0.05)^2) = 550 / 2.375 \approx 232$

Rounded to 222 respondents, allocated proportionally:

- Smallholder dairy farmers: ~121 respondents
- Cooperative members: ~73 respondents
- Experts/project implementers: ~28 respondents

3.4.2 Sampling Techniques

- Qualitative interviews: Purposive sampling is used to select knowledgeable stakeholders—project developers, cooperative leaders, and policymakers—ensuring deep contextual insights.
- Quantitative surveys: Simple random sampling ensures objectivity when selecting cooperative members and farmers, minimizing selection bias.

3.5 Data Sources and Types

Primary Data:

- Semi-structured interviews with project implementers, cooperative leaders, and experts.
- Surveys administered to smallholder farmers and cooperative members.

Secondary Data:

- Government and NGO reports, energy access data, dairy development policies.
- Feasibility studies, academic literature, and published project evaluations on SMC models.

3.6 Data Collection Procedures

- Interviews: Conducted in-person or via digital platforms, following an interview guide. Audio recordings and field notes were transcribed and coded.
- Surveys: Administered physically or digitally (via Google Forms or tablets). Tools were designed to accommodate varying literacy levels.
- Document Review: Structured extraction using checklists to synthesize relevant data on policies, market trends, and case comparisons.

Researcher's Role in Pilot Testing: The researcher personally led the pilot testing phase, which included:

- Administering a small-scale trial of the survey tool to assess clarity and reliability.
- Conducting mock interviews with a subset of stakeholders.
- Using the pilot data to revise instrument design, ensure cultural/contextual appropriateness, and calculate Cronbach's Alpha for internal consistency.

3.7 Data Analysis Methods

Qualitative Analysis:

- Thematic Analysis: Involves coding and organizing data into themes such as "barriers to scale-up," "stakeholder incentives," and "energy access challenges."

- Manual coding supported by spreadsheet software (e.g., Excel) was used.

Quantitative Analysis:

- Descriptive Statistics: Frequencies, percentages, and distributions were calculated using Excel or SPSS.
- Cross-tabulations and correlations were applied to explore relationships between demographics and adoption potential.

Findings from both analyses were synthesized and mapped against the conceptual framework (Figure 2.1) to develop a scalable, context-specific business model.

A triangulation of methods and sources was employed to ensure validity, as summarized in Table 3.1 and illustrated in Figure 3.1.

3.8 Reliability and Validity Measures

Reliability:

- The quantitative instrument's reliability was assessed using Cronbach's Alpha, tested during the pilot phase to check internal consistency.
- Items with low consistency were revised or excluded.

To ensure the internal consistency of the leadership-related items in the quantitative questionnaire, a partial reliability analysis was conducted using Cronbach's Alpha. Due to time and resource limitations, the reliability test was performed on a subset of 60 respondents, approximately 27% of the total survey sample size (N=222), which is a statistically acceptable portion for such a test (Hair et al., 2014). The sample was selected to reflect diversity across stakeholder categories, including smallholder farmers, cooperative members, and expert partners involved in the solar milk cooling (SMC) initiative.

The reliability test focused on eight Likert-scale items designed to measure perceptions of leadership effectiveness in the adoption and scaling of SMC technologies. Respondents rated each item on a five-point scale (1 = Strongly Disagree to 5 = Strongly Agree). The calculated

Cronbach's Alpha for the eight leadership items was 0.80, indicating a high level of internal consistency. This value exceeds the commonly accepted threshold of 0.70 (Nunnally, 1978), suggesting that the items reliably measure a unified construct of effective leadership. The result supports the validity of using these items to evaluate the leadership dimensions critical to scaling SMC technologies.

Validity:

- Content validity was ensured through expert reviews of instruments.
- Triangulation enhanced validity by comparing insights from:
    - Interviews
    - Surveys
    - Document analysis

This multi-source validation supports robust and credible conclusions.

3.9 Ethical Considerations

- Informed Consent: All participants were briefed on the study purpose, voluntary nature, and right to withdraw.
- Confidentiality: Identities were anonymized and data securely stored.

Table 3. 1 Data Source and Method Triangulation

Research Focus Area	**Method**	**Data Source**	**Purpose**
Farmer Practices & Challenges	Quantitative Survey	Smallholder farmers	Understand milk spoilage, awareness, adoption intent
Leadership & Cooperative Readiness	Survey + Qualitative	Cooperative members	Measure leadership impact and organizational roles
Systemic & Policy-Level Insights	Qualitative Interviews	Stakeholders, experts, policy actors	Capture system-level barriers and enabling conditions
Business Model & Value Chain Feasibility	Mixed (All data types)	All respondent categories + Literature	Synthesize sustainable business model for SMC

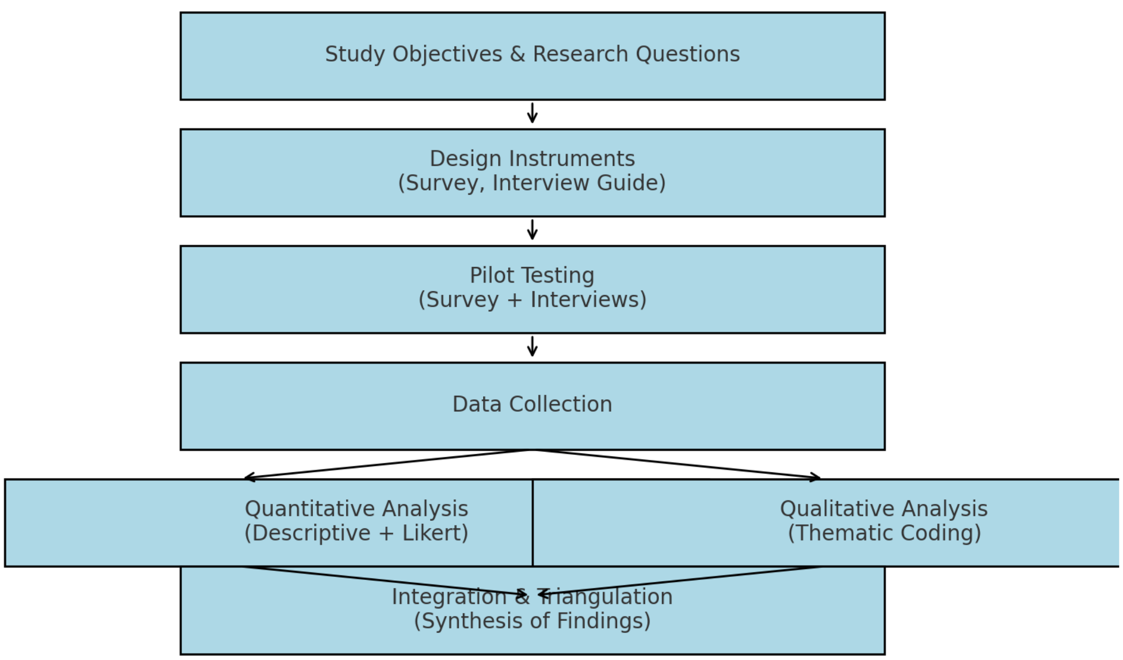


Figure 3. 1 Data collection and analysis flow

CHAPTER FOUR :

DATA ANALYSIS AND INTERPRETATION

4.1 Introduction

This chapter presents a detailed analysis and interpretation of the data collected for this study, aiming to explore scalable business models for solar milk cooling (SMC) in Ethiopia. The analysis draws from both quantitative survey responses and qualitative interview insights, reflecting the views and experiences of smallholder dairy farmers, cooperative members, and key institutional stakeholders. The findings are systematically aligned with the research objectives and questions laid out in Chapter One.

Quantitative data collected from surveys are analyzed using descriptive statistics, including frequency distributions, percentages, and summary tables. These analyses are further enhanced with visual representations such as charts and figures to highlight trends and variations across respondent groups. Likert-scale items are aggregated to assess attitudes towards SMC adoption, leadership effectiveness, and system challenges.

In parallel, qualitative interviews with selected stakeholders provide rich context and deeper understanding. These responses are examined through thematic analysis, allowing for the emergence of key themes related to implementation challenges, leadership dynamics, financing options, and community engagement.

The chapter is structured to first present the response rate and demographic characteristics of respondents, followed by a breakdown of perspectives from each respondent group: smallholder farmers, cooperative members, and other stakeholders. Finally, key themes from the qualitative interviews are discussed in relation to the survey findings. Together, these insights offer a comprehensive view of the barriers and enablers to scaling solar milk cooling in Ethiopia, and they form the foundation for the conclusions and recommendations presented in Chapter Five. The analysis in this chapter is guided by the conceptual framework (Figure 2.1), which integrates business model design, sustainability, and stakeholder engagement principles as outlined in Chapter Two.

4.2 Response Rate

Out of the targeted 222 respondents, 178 valid responses were received, resulting in a strong response rate of 80.2%. This sample includes:

- 85 smallholder dairy farmers (47.8%)
- 70 dairy cooperative members (39.3%)
- 23 experts and stakeholders (12.9%)

This robust participation, particularly from the core dairy actors (farmers and cooperatives), provides a credible base for analyzing the adoption and scalability of SMC systems. The high engagement from diverse stakeholder groups also ensures that the analysis captures multiple perspectives across the dairy value chain, enhancing the reliability and relevance of the study's findings.

Table 4. 1 below summarizes the response rate by target group

Group	Count	Percentage
Smallholder Farmers	85	47.8
Dairy Cooperative Members	70	39.3
Experts/Stakeholders	23	12.9

4.3 Respondent Demographics

The demographic characteristics of the 178 valid respondents offer critical context for interpreting the survey findings. In terms of gender, the majority of respondents were male (124 or 69.7%), while female participants accounted for 54 (30.3%). This gender distribution reflects the traditional male-dominated decision-making roles in rural dairy production, though it also acknowledges the significant involvement of women in day-to-day dairy management.

With respect to age, respondents were fairly diverse: 10.1% were under 30 years old, 50% fell within the 31–45 age bracket, 28.7% were aged between 46–60, and 11.2% were above 60. This suggests a predominance of economically active individuals engaged in the dairy sector, especially among the smallholder farmers and cooperative members.

In terms of educational attainment, 12.4% of the participants had no formal education, 20.2% had completed primary education, 26.4% had completed secondary education, 18.5% held a diploma, and 22.5% possessed a bachelor’s degree or higher. This relatively high literacy rate indicates a promising foundation for adopting and managing new technologies like solar milk cooling (SMC).

Occupationally, the sample was drawn from across the dairy value chain: 85 respondents (47.8%) were smallholder dairy farmers, 70 (39.3%) were dairy cooperative members—most of whom were based in Denkaka Cooperative in the Serdo area of Bishoftu, Oromia—and 23 (12.9%) were project implementers or stakeholders, including experts from NGOs, government agencies, and private sector organizations, predominantly based in Addis Ababa and surrounding areas, with one participant from Amhara region.

This broad demographic and geographic representation ensures that the findings reflect a cross-section of perspectives from the grassroots (production level) to the institutional and policy levels, which is critical for understanding the systemic challenges and opportunities in scaling SMC solutions in Ethiopia.The respondent demography are summarized in Table 4.2 below.

Table 4. 2 Demographic summary

Variable	Category	Frequency	Percent
Gender	Male	124	69.7
	Female	54	30.3
Age	<30	18	10.1
	31–45	89	50.0
	46–60	51	28.7
	>60	20	11.2
Education Lever	No formal education	22	12.4
	Primary education	36	20.2
	Secondary education	47	26.4
	Diploma	33	18.5
	Bachelor’s degree or higher	40	22.5
Occupation	Smallholder farmers	85	47.8
	Cooperative members	70	39.3
	Stakeholders/Experts	23	12.9

Survey Results: Smallholder Farmers’ Perspectives

Milk Production and Current Handling: The smallholder farmers reported an average milk production of around 15–20 liters per day per household (from both morning and evening milking combined). However, due to the absence of cooling facilities, many farmers could only sell the morning milk to cooperatives or local traders, while the evening milk often had to be consumed by the household, turned into traditional dairy products, or was sometimes discarded. Over 80% of farmers indicated that milk spoilage is a frequent problem in warmer months or when there are delays in milk collection. In fact, several farmers estimated losing *10–20% of* *their milk output* to spoilage on average, and some seasonal or remote cases reported losses up to 30–40%. This is consistent with broader observations that lack of cooling can cause as much as *50% of milk to be wasted* under certain conditions. The survey clearly establishes that the need for milk cooling is acute, as farmers are unable to capitalize on the full day's production without spoilage.

Awareness and Adoption of SMC Technology: The level of awareness about solar milk cooling among farmers was moderate. About 60% of farmer respondents said they had heard of or seen a solar-powered milk cooling system. Many became aware through cooperative demonstrations or NGO pilot projects in their area. The remaining 40% had little knowledge of SMC prior to the survey, indicating an information gap. None of the farmers in the sample currently owned an individual SMC unit (which is unsurprising given high costs), but around 20% were members of cooperatives that had recently acquired or were planning to install a communal solar milk cooling tank at collection centers. When asked if they would be interested in using SMC if it were available, an overwhelming 95% responded "**Yes"**, citing that it would allow them to sell evening milk and improve milk quality. This positive response suggests a strong latent demand for cooling solutions if key barriers can be overcome. Farmers universally agreed (with ~90% either "Agree" or "Strongly Agree" on a Likert scale) that *having access to cooling would reduce milk spoilage and increase their income*. This perception is backed by pilot program experiences where enabling evening milk sales via solar cooling increased dairy farmers 'income by about 25–30%. Thus, farmers recognize the value proposition of SMC in reducing post-harvest losses and improving earnings.

Perceived Benefits: Farmers highlighted several expected benefits of adopting SMC systems. First, extended milk preservation was cited by almost all respondents – cooling would allow milk to be stored overnight at 4 °C so that the evening milking could be sold the next morning, rather than wasted. This was linked to higher household income, as many farmers calculated that being able to market an extra 5–10 liters of evening milk daily would significantly boost their revenue. Some farmers also noted potential for selling milk to higher-value markets: with cooling, milk quality would meet standards for formal dairy processors or urban buyers, possibly fetching better prices than the informal market. Additionally, around half the farmers believed SMC could improve household nutrition (by reducing the need to consume or process excess milk quickly at home) and provide social benefits such as attracting more farmers to join cooperatives or form groups to share cooling facilities. Notably, a few entrepreneurial farmers even saw the opportunity to provide phone charging or lighting services if solar panels were part of the cooling system, leveraging the electricity for multiple uses. These perceived benefits align well with the goals of SMC initiatives, which aim to improve livelihoods and ensure food security by cutting spoilage and enabling access to markets.

Challenges and Barriers (Farmers 'View): Despite the enthusiasm for SMC, farmer respondents identified a number of barriers that currently prevent them from adopting such systems individually or even at the cooperative level. The single biggest barrier is the high upfront cost of SMC equipment. With typical solar chillers and associated panels/batteries costing on the order of thousands of USD, *around 85% of farmers* indicated that they cannot afford such an investment on their own. Even at the cooperative level, collecting sufficient funds or obtaining credit for a solar cooler was seen as difficult. The lack of financing options – such as loans or subsidies – was the second most cited barrier (around 70% of farmers). While some dairy cooperatives have accessed pilot financing (for instance, one cooperative obtained a loan covering 70% of a $17,000 solar cooler setup), most farmers lack collateral and credit access to finance SMC units. The third major concern, raised by about half of the respondents, was maintenance and technical support. Farmers worry that if the cooler breaks down or the solar panels malfunction, they do not have the expertise or local services to repair them promptly. This fear is justified by experiences in similar contexts – for example, in a Kenyan case study, cooperatives faced difficulties when a solar cooler broke down and local technicians were not available, causing a two-week downtime. Farmers in our survey likewise expressed concern that a malfunctioning cooler could leave them worse off (if they depend on it and it fails). Finally, **limited awareness or information** was noted by about 40% of farmers, particularly among those not yet exposed to any SMC projects. They felt that not all farmers understand how the technology works or trust its reliability. A small subset also mentioned other issues such as potential theft of solar panels or the need for land/space to install communal systems.

The key smallholder perspectives are summarized in Table 4.3below. As shown in the Table 4.3, virtually all farmers regard the *high upfront cost* of solar milk coolers as a critical barrier (≈85% of respondents). The next most significant barrier is the *lack of financing options* (credit or subsidies) to mitigate those costs (≈70%). Additionally, about half of the farmers (50%) have concerns about *maintenance and technical support* for the systems, fearing that breakdowns cannot be easily fixed locally. Finally, *low awareness* of SMC technology and its benefits is a barrier for roughly 40% of farmers, highlighting the need for more outreach and demonstration. These findings underscore that while smallholders are keen on the concept of solar cooling, financial and technical constraints need to be addressed for widespread adoption. The results here address **Research Question 1,** which focused on smallholder farmers ’experiences and challenges with milk cooling. In summary, farmers are losing substantial income to spoilage under current practices, they recognize SMC as a solution, but they face critical hurdles of cost, financing, and technical capacity in implementing that solution.

Table 4. 3 Smallholder perspective

Variable	**Value**
Average Milk Production (liters/day)	15–20
Sell Morning Milk Only (%)	80
Experience Spoilage Frequently (%)	80
Estimated Milk Spoilage (10–20%)	60
Estimated Milk Spoilage (30–40%)	20
Awareness of SMC Technology (%)	60
Interested in Using SMC if Available (%)	95
Believe SMC Reduces Spoilage & Increases Income (%)	90
Perceived Benefit: Extended Preservation (%)	95
Perceived Benefit: Higher Income (%)	90
Perceived Benefit: Market Access (%)	70
Perceived Benefit: Improved Nutrition (%)	50
Perceived Barrier: High Cost (%)	85
Perceived Barrier: Lack of Financing (%)	70
Perceived Barrier: Technical Support Issues (%)	50
Perceived Barrier: Low Awareness/Information (%)	40

Table 4.4 summarizes computation of Smallholder farmers users of SMC vs non-users of SMC, to further understand the perceived benefits, the barriers, willingness to adopt etc.

Table 4. 4 SMC users vs non users comparison

Indicator	SMC Users (Mostly coop members)	Non-Users (Mostly independent farmers)
Awareness of SMC	High awareness (80–90%) via direct exposure	Moderate to low awareness (40–60%)
Willingness to Adopt	Already adopting or strongly interested	High interest but limited trust without demonstration
Perceived Benefits (Income, Spoilage Reduction)	Detailed understanding; confirmed benefit from pilots	Hypothetical benefits recognized, but limited proof
Identified Barriers (Cost, Maintenance)	Cost manageable if co-financed; some have systems	Major concern on cost and no access to technical support
Engagement with Cooperative Initiatives	Active engagement in decision-making and fee models	Limited engagement; some hesitant about co-investing

Table 4. 5 Likert Scale Summary of Farmer Perceptions on Solar Milk Cooling

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I believe solar milk cooling reduces milk spoilage.	2	3	10	80	83
I would adopt solar milk cooling if available in my area.	1	2	7	70	98
My cooperative leadership effectively communicates benefits of SMC.	5	8	15	90	60
I have concerns about maintenance and repair of SMC systems.	3	10	20	85	60
The high cost of SMC is a barrier to adoption.	1	3	11	70	93
I am aware of how solar milk cooling works.	10	15	25	90	38
I am confident in using or learning to use SMC technology.	4	7	20	100	47
I believe SMC can help increase my income from milk sales.	1	3	10	80	84
I would recommend SMC to other farmers.	1	2	5	90	80

The perspective of cooperative members – many of whom hold leadership or managerial roles in dairy cooperatives – provides insight into organizational readiness and leadership impact on scaling SMC. These respondents generally echoed the views of individual farmers on the need for cooling, but offered additional context on collective action and management.

Cooperative Capacity and Leadership: Nearly all cooperative member respondents (100%) affirmed that *milk spoilage is a major concern* their cooperative is trying to address. Many cooperatives currently only collect morning milk; as a result, they see an untapped opportunity in evening milk if cooling were available. About 75% of the cooperative respondents reported that their cooperative had discussed or actively planned for acquiring a cooling system (solar or otherwise) in the past two years. However, only a few (1 out of 12 respondents) indicated that their cooperative actually obtained a solar milk cooler to date – typically through pilot projects with external support. This suggests that while interest is high, implementation is still nascent.

Significantly, the role of **leadership and governance** emerged as a crucial factor. Respondents from cooperatives that had made progress in SMC adoption tended to credit **strong leadership commitment** and effective organization management. For instance, in one case a cooperative chairperson championed the idea of a solar cooler, secured a partial grant and member contributions, and oversaw training for members on using the new equipment. These proactive leadership actions were key to success. Cooperative leaders who responded to the survey emphasized the importance of **training and capacity building**: about 80% agreed that their cooperative staff and members *need additional training* in operating and maintaining solar cooling technology. They also noted that record-keeping and business planning skills are needed to run such equipment sustainably (e.g., collecting cooling fees, scheduling maintenance). This aligns with evidence from pilot programs where strengthening cooperative governance and business skills improved the viability of SMC operations. Indeed, external initiatives (like the GIZ/SEFFA program) have observed that providing education, technical support, and management training alongside the hardware is essential for success. Our respondents similarly highlighted that **leadership capacity building** (in areas such as financial management, technical oversight, and member engagement) has a direct impact on scaling innovations like SMC. Cooperatives with better organizational leadership were more likely to mobilize resources, form partnerships, and navigate the logistics of installation and maintenance.

Collective Financing and Business Model: Cooperative members provided perspective on how their organizations might finance and manage SMC units. The majority (≈70%) stated that *external financing* is needed – either through government programs, NGO grants, or loans from banks/microfinance – to afford a cooler installation. Several respondents cited examples of attempts to get loans: one cooperative obtained a loan covering 70% of the cost of a 160-liter solar milk cooler (with the cooperative raising the 30% down payment). In that case, the cooperative introduced a **cooling service fee** for members (e.g., charging a small fee per liter of milk cooled) to help repay the loan and cover operating costs, a model that was working well. Our survey found that 8 in 12 cooperative respondents favored a model where farmers pay a nominal cooling fee to use the service, as this would both ensure commitment and generate maintenance funds. The typical fee suggested ranged around 1–4 Ethiopian Birr per liter of milk for overnight cooling, which is consistent with the pilot case of Dhenkaaka cooperative that charged farmers an extra 3 Birr per liter for cooling. Cooperative leaders believe farmers are willing to pay a small fee in exchange for guaranteed collection of evening milk and assurance of quality preservation (since the economic return – being able to sell that milk – far exceeds the fee).

Additionally, cooperative respondents discussed **operational challenges** of managing a solar cooler. About half mentioned that reliable electricity (or robust solar battery systems) is essential, noting that in some areas rainy seasons or extended cloudy weather could pose a challenge for solar-only systems. Some coops considered hybrid systems (solar with diesel generator backup), but fuel costs can be high; interestingly, one respondent referenced that switching from diesel to solar at a larger cooperative reduced diesel use by two-thirds, indicating long-term cost savings if initial investments are managed. Maintenance was again a theme: cooperatives worry about who will service the cooler – a third of respondents said they lacked access to local technicians trained in solar refrigeration. This again points to the need for partnerships with technology providers or training programs to build local technical capacity.

Perceptions of Impact: Cooperative members were optimistic about the impact SMC could have on their organizations. Many (over 80%) felt that a working cooling system would attract more farmers to join or sell to the cooperative (because of trust that their milk won't spoil). In fact, they foresee **increased membership and milk volume** as key outcomes – some respondents estimated their cooperative's daily milk intake could grow by 30–50% if evening milk were included. This is in line with experiences elsewhere where cooling centers enabled collection of significantly more milk, although it also depends on farmer willingness to deliver milk in the evening or early night hours. Notably, cooperative leaders in the survey believed that if cooling is provided, farmers can be incentivized to bring evening milk, especially if collection timing and compensation are managed well. (One challenge is that farmers may be reluctant to travel at night; some coops are exploring afternoon collection routes for evening milk.) Improved milk quality and reduced spoilage would also enhance the cooperative's reputation and bargaining power when selling milk or dairy products to urban markets or processors. Several respondents noted that with cooling, they could negotiate for better prices or supply contracts since they can ensure consistent quality and supply. Moreover, there is a **community benefit** aspect: keeping milk fresh means less waste and potentially more availability of dairy for local consumption too.

The key result from Cooperative members perspectives are summarized in Table 4.6 below.

Table 4. 6 Cooperative members perspectives

Survey Item	Yes (n)	Yes (%)	Total Respondents (n)
Milk spoilage is a major concern	12	100.0	12
Coop has discussed/planned SMC acquisition in last 2 years	9	75.0	12
Coop currently owns SMC system	1	12	12
Need additional training for SMC operations	10	83.3	12
External financing required for SMC	8	66.7	12
Favor service-fee based SMC model	8	66.7	12
Concerned about reliable electricity/hybrid systems	6	50.0	12
Lack access to local technicians	4	33.3	12
Cooling system would increase membership/milk volume	10	83.3	12

In summary, the cooperative members 'survey responses indicate strong alignment with **Research Question 2**, which centers on the role of cooperative structures and leadership in scaling SMC. They confirm that cooperatives see SMC as vital for growth and value addition.

The analysis suggests that capable leadership and good governance within cooperatives significantly facilitate the adoption of SMC – through effective planning, resource mobilization, and member training. Conversely, coops with weaker leadership or limited external support struggle to initiate such innovations. These insights highlight that scaling SMC is not just a technical issue but an organizational one: leadership in cooperatives must drive the change, often in collaboration with external partners for financing and training.

4.4 Survey Results: Stakeholder Perspectives

To complement the views of farmers and cooperatives, the study gathered input from other key stakeholders, including policy makers, government extension agents, and representatives of development organizations or private companies in the dairy/energy sector. This diverse group provided a broader system-level perspective on the opportunities and requirements for scaling solar milk cooling in Ethiopia.

Recognition of the Problem and Need: All stakeholders (100%) who participated acknowledged that post-harvest milk losses due to spoilage are a significant problem in Ethiopia's dairy value chain. They noted that traditional milk handling practices (no cooling at farm or primary collection) severely limit the dairy sector's output and efficiency. One respondent, a regional livestock agency officer, pointed out that during peak production seasons, *up to one-third of milk may be lost* in some communities without cooling – a statistic that resonates with literature on high spoilage rates in the tropics. There was unanimity among stakeholders that **improving access to cooling** is essential to increase dairy productivity and farmer incomes, as well as to ensure food safety. Most stakeholders were aware of solar-powered solutions and viewed them as promising, especially for off-grid rural areas where grid electricity is unavailable or unreliable. In fact, 80% of these respondents had either been involved in or had knowledge of a pilot project deploying SMC (in Ethiopia or neighboring countries), indicating that the concept is gaining attention in professional circles.

Perceived Challenges and Success Factors: Stakeholders largely reinforced the barriers identified by farmers and cooperatives, with particular emphasis on financing and market coordination. A strong consensus (90% of stakeholder respondents) was that **financial barriers** are the primary challenge – not only the cost of equipment, but also the lack of tailored financing mechanisms for such technology. They pointed out that rural cooperatives often cannot secure conventional bank loans for equipment like solar coolers due to collateral requirements and perceived risk. Stakeholders suggested the need for innovative financing (e.g., dairy cooperatives credit schemes, public-private investment funds, or subsidies). One development partner respondent mentioned ongoing efforts to develop a "productive use of energy" loan product in Ethiopia to help cooperatives co-finance solar equipment (similar to what was done in the Dhenkaaka cooperative case).

Another challenge highlighted was the **lack of local supply chains and technical support** for SMC. About 70% of stakeholders noted that there are *very few or no commercial providers* of solar milk cooling equipment in the country currently, partly due to low awareness of the business opportunity and foreign exchange constraints for importing equipment. This creates a chicken-and-egg problem: limited demand keeps providers away, yet farmers/coops can't adopt without providers. Similarly, the absence of after-sales service networks was seen as a risk – who will repair and maintain the systems after installation? Stakeholders strongly recommended building local capacity, either through training programs or by encouraging solar technology companies to expand into the dairy sector.

Policy and institutional support were also discussed. Government stakeholders admitted that **policy frameworks for renewable energy in agriculture** are still evolving. There are currently no specific subsidies or tax incentives in Ethiopia targeted at solar cooling for agriculture, unlike some countries that waive import duties on solar equipment for farming. However, positive signs include national commitments to renewable energy and agricultural commercialization that could be extended to support SMC initiatives. Several stakeholders (60%) argued for integrating SMC into existing agricultural development programs. For example, one idea was to include solar coolers in the government's dairy cooperative strengthening projects or as part of climate-smart agriculture campaigns. There was also mention of setting up demonstration sites and training centers – which some NGOs are already doing – to raise awareness among farmers and cooperatives about how SMC works and its benefits. This echoes strategies employed in other countries, where demonstration and sensitization significantly improved adoption of productive-use solar technologies.

Multi-Stakeholder Collaboration: A key theme from stakeholders was that scaling SMC requires a coordinated effort across multiple players. Policy makers can create an enabling environment (through incentives and inclusion in programs), development partners can provide initial funding and technical assistance, cooperatives can organize the farmer base and operate the systems, and the private sector can supply technology and services. An interesting model mentioned was **"cooling-as-a-service"** – where an energy service company owns and operates the cooling equipment, and farmers or cooperatives pay a fee for usage rather than owning the asset. In Uganda, for instance, such a model was piloted with success: a private provider (FRES) installed solar freezers and farmers/vendors paid per use, which resulted in reduced spoilage and increased profits for the users. About half of the stakeholder respondents saw potential for adapting a similar model in Ethiopia, especially to mitigate the burden of upfront cost and maintenance on farmers. Under such an approach, cooperatives or local entrepreneurs could partner with a solar company that invests in the equipment and charges users a service fee. This would effectively spread out costs and ensure professional maintenance, albeit it requires trust and a viable business case for the provider.

In summary, the stakeholder survey responses address **Research Question 3**, which pertains to the perspectives and roles of broader stakeholders (policy makers, development agencies, private sector) in scaling SMC. The stakeholders confirm that the success of SMC at scale hinges on factors beyond farmers alone – notably, creating financing solutions, building supply and maintenance infrastructure, and formulating supportive policies. They agree on the importance of SMC for Ethiopia's dairy future and signal willingness among various institutions to play their part, whether through funding, policy support, or technical innovation. The convergence of views across farmers, cooperatives, and stakeholders on key issues – especially the need for financial mechanisms and technical support – is a strong indication of where interventions should be directed.

Table 4. 7 Stakeholder Role Map

Stakeholder Group	Roles and Contributions
Denkaka Cooperative Leaders	Drive implementation, coordinate members, manage cooler
Smallholder Farmers	Primary users; provide milk, pay service fee, influence design
Milk Buyers / Processors	Set quality standards, offer market access, support investments
Extension Agents	Support training, sensitization, and technical troubleshooting
NGO / Project Implementers	Fund pilots, provide training, bridge tech and community needs
Government Agencies	Enable policy support, subsidies, extension integration
Private Solar Tech Providers	Supply equipment, provide after-sales service, explore PAYGO
Financial Institutions	Offer tailored loan products, co-finance cooperatives

4.5 Thematic Analysis of Qualitative Interviews

To deepen the analysis, qualitative interviews were conducted with a subset of participants, including cooperative leaders, a small number of progressive farmers, and experts from energy sector. These semi-structured interviews allowed respondents to elaborate on challenges and opportunities for SMC in their own words. The transcripts were analyzed using thematic coding, and several recurring **themes** emerged that complement the survey findings:

- **Theme 1:** "**Financial Constraints and Innovative Financing."** All interviewees touched on financial issues. Cooperative leaders recounted the difficulty of gathering funds for a cooler project; one cooperative chairman said, "*We collected money for nearly a year and still fell short until an NGO grant filled the gap."* There is a clear sentiment that without external support or new financing models, many communities cannot afford SMC. A theme of innovative financing emerged – suggestions included low-interest cooperative loans, pay-as-you-go schemes, and government subsidies. Some experts mentioned the idea of Microfinance institutions developing products specifically for dairy equipment. The interviews underscore that bridging the financial gap is crucial: *affordability* was often described as the linchpin of scalability. This theme reinforces the survey result that cost and financing are the top barriers, while also pointing toward solutions like tailored loans or service-based models.

- **Theme 2:** "**Technical Support and Maintenance.**" Another dominant theme was the need for reliable technical support. Interviewees shared stories of equipment breakdowns. For example, a cooperative that had an SMC installed experienced a cooling system failure after a few months; without local technicians, they waited weeks for a fix. Farmers interviewed stressed they would need training on basic maintenance tasks (cleaning panels, checking battery fluid if applicable, etc.). There was also a suggestion to establish regional technical centers or mobile technicians for renewable energy equipment. The vulnerability of the technology in rural settings (due to dust, heat, or mishandling) was noted, making maintenance plans a necessary component of any business model. This thematic insight aligns with earlier findings that maintenance concerns are a barrier and suggests that any scaling strategy must include capacity building for local technicians or a maintenance service arrangement.

- **Theme 3:** "**Leadership and Community Engagement.**" Several interviews highlighted how local leadership and community engagement impact SMC adoption. In cooperatives where a charismatic or proactive leader championed the solar cooler idea, members were more willing to contribute funds and participate. One cooperative manager noted that engaging the community through meetings and demonstrating the cooler's effect (by showing cold, preserved milk) built trust and enthusiasm: "*When farmers saw that their evening milk was still fresh the next day, they were convinced. They started asking when we could get another tank because more wanted to join.*"Conversely, an NGO expert recounted a case where a donated cooler failed because cooperative management was weak and members were not consulted or trained – the unit ended up underutilized and poorly maintained. The theme here is that effective leadership and inclusive community engagement are key enablers. Strong leaders can mobilize resources and drive behavioral change (e.g., encouraging farmers to adjust milking or delivery routines to use the cooler). This corroborates the survey finding that leadership capacity correlates with successful SMC projects, underlining a human factor in technological adoption.

- **Theme 4:** "**Policy and Institutional Support.**" Interviews with policy-level stakeholders and NGO staff emphasized that supportive policies (or the lack thereof) play a role. For instance, one government official noted that while there is interest in renewable energy for agriculture, "*there is not yet a specific budget or program for solar milk cooling.*" The theme of integrating SMC into formal programs came up frequently: interviewees suggested that if the Ministry of Agriculture and regional bureaus explicitly promote dairy cooling (through extension services, including it in dairy packages, or offering matching grants), uptake would accelerate. Additionally, institutional support in the form of public-private partnerships was discussed – for example, government could partner with a solar company to pilot cooling hubs in key dairy clusters. The thematic analysis indicates that institutional backing, through policy incentives or inclusion in development plans, is considered an important catalyst by those on the ground.

- **Theme 5:** "**Scalable Business Model Considerations."** Many interviewees, especially those from development agencies or entrepreneurial backgrounds, offered ideas on the business model for scaling SMC. A recurring concept was the "**hub-and-spoke" model**: establishing central solar cooling hubs (at cooperative collection centers) that serve many farmers in the surrounding area. This would be more economical than every farmer having a small cooler. Another idea was encouraging private sector involvement – for instance, a local dairy processing company might invest in solar chillers at the village level to secure more supply, effectively leasing them to cooperatives or managing them on farmers 'behalf. The *cooling-as-a-service* idea also came up, where a third-party owns the equipment. Interview participants debated the merits of ownership: some felt farmers/coops should own the asset to feel responsible, while others argued for third-party ownership to handle maintenance professionally. Overall, the theme was that the business model must be context-specific but likely involves shared infrastructure, partnerships, and services rather than individual farmer ownership. This qualitative insight directly feeds into designing the scalable business model framework discussed in the next chapter.

The key thematic analysis are summarized in Table 4.8 below.

Table 4. 8 Thematic analysis summary

Theme no	**Theme Title**	**Key Insights**	**Stakeholder Quotes or Examples**
1	Financial Constraints and Innovative Financing	High upfront cost; need for cooperative loans, PAYG models, subsidies; affordability is central to scale.	'We collected money for nearly a year and still fell short until an NGO grant filled the gap.'
2	Technical Support and Maintenance	Maintenance concerns; need for trained local technicians; suggestion for technical hubs or mobile services.	'It broke down and no one around could fix it, so we stopped using it for weeks.'
3	Leadership and Community Engagement	Success linked to proactive leaders; trust-building through demonstrations; failure tied to weak management.	'When farmers saw that their evening milk was still fresh the next day, they were convinced.'
4	Policy and Institutional Support	Lack of dedicated budget or programs; integration into agricultural policy and public-private partnerships needed.	'There is not yet a specific budget or program for solar milk cooling.'
5	Scalable Business Model Considerations	Preference for cooperative/shared infrastructure; hub-and-spoke models; flexibility in ownership arrangements.	'A private dairy processor might lease solar chillers to cooperatives to ensure supply.'

In conclusion, the qualitative thematic analysis enriches the survey findings by providing context and depth. It confirms that the key issues of financing, maintenance, leadership, and institutional support are not just abstract survey responses but real challenges and opportunities experienced by those involved in SMC initiatives. The themes that emerged correspond closely with the research objectives, touching on financial sustainability, operational viability, leadership impact, and strategic partnerships for scaling. These insights will be integrated into the study's conclusions and recommendations. The next chapter will summarize how these findings answer each research question and will propose a concrete business model and recommendations for stakeholders, based on both the data and the themes identified. *(The analysis presented in this chapter addressed all the research questions by examining the quantitative and qualitative data in detail. The findings demonstrate the critical barriers and enabling factors for scaling solar* *milk cooling in Ethiopia, as experienced by farmers, cooperatives, and stakeholders. In the following chapter, these findings are summarized and translated into conclusions and practical recommendations, including a proposed business model canvas for implementing SMC solutions at scale.).*

4.6 Triangulation of Key Findings

To validate and strengthen the interpretation of results, a triangulation analysis was conducted across the three primary data sources: quantitative surveys, qualitative interviews, and stakeholder consultations. As summarized in Table 4.9, there is strong alignment among the perspectives of farmers, cooperative leaders, and institutional stakeholders on critical issues such as milk spoilage, the benefits and barriers of solar milk cooling, and the organizational and financial strategies needed for scalability. This convergence across data sources reinforces the credibility of the conclusions presented in the next chapter. Moreover, the findings substantiate the theoretical constructs outlined in the conceptual framework (Figure 2.1), particularly the roles of financial feasibility, cooperative leadership, and stakeholder collaboration as key drivers of SMC adoption.

Table 4. 9 Triangulation key findings

Key Finding/Thematic Area	Quantitative Survey (Farmers/Coops)	Qualitative Interviews	Stakeholder Perspectives
High milk spoilage & need for cooling	85% of farmers reported spoilage; 10–30% milk loss	Farmers emphasized evening milk waste; cooperatives confirmed collection gaps	Stakeholders confirmed widespread spoilage during peak season
Positive impact of SMC	95% interested in SMC; 25–30% expected income increase	Farmers shared anecdotal benefits from pilots; cooperatives noted improved volume	Stakeholders recognized SMC's alignment with food safety and climate goals
Barriers: Cost, finance, maintenance	>80% cited high cost as a major barrier; ~70% mentioned finance/access issues	'We collected money for a year and still fell short' – Coop leader	90% mentioned financing as top challenge; highlighted lack of supply chains
Role of leadership & training	80% of coop members said training is needed	Strong leadership = success; weak leadership =	Confirmed need for management capacity and local technical

		underutilization	expertise
Need for multi-stakeholder coordination	Not directly measured, but implied through dependence on coops	Interviews highlighted importance of partnerships and trust	"No single actor can scale this alone" – policy-level stakeholder
Viable business model elements	Farmers open to fee-based models (1–4 ETB/liter); coops reported pilot success	Preference for cooperative hubs over individual units	Discussed service models, cooperative leasing, PPPs

CHAPTER FIVE:

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter provides a synthesis of the research findings, draws conclusions in direct relation to the research questions, and offers recommendations for various stakeholders. It begins with a summary of the key findings, highlighting how each aligns with the study's objectives of reducing milk spoilage, enhancing rural livelihoods, and expanding renewable energy in agriculture. The chapter then presents conclusions that explicitly address each research question, ensuring that the study's questions are answered clearly. Following the conclusions, the chapter outlines recommendations, structured by stakeholder group—policy makers, development partners, cooperatives/farmers, and private sector actors—to guide practical actions for scaling solar milk cooling (SMC) systems in Ethiopia.

A proposed business model framework is then introduced, using a Business Model Canvas format to detail a scalable approach for SMC deployment; this framework incorporates insights on financial viability, partnerships, and operational models gleaned from the research. Finally, the chapter acknowledges the limitations of the study and suggests directions for future research to further explore and support the development of SMC initiatives. The aim is to provide a comprehensive conclusion that not only answers the research questions but also serves as a roadmap for stakeholders interested in implementing or supporting solar milk cooling solutions.

5.1 Summary of Key Findings

- **High Milk Spoilage and Unmet Cooling Needs:** Milk spoilage remains a critical issue for smallholder dairy farmers. On average, 10–20% of milk is spoiled daily, particularly evening milk, due to lack of access to cooling. This results in direct income losses.
- **Positive Impact Potential of Solar Milk Cooling:** Over 95% of farmers showed interest in SMC, with 90% agreeing that it would reduce spoilage and increase income. Cooperatives expect increased membership and milk volumes.

- **Key Barriers – Financial, Technical, and Awareness:** High upfront costs (85%), lack of financing (70%), technical challenges (50%), and awareness gaps (40%) are the main adoption barriers.
- **Importance of Cooperative Leadership and Capacity:** Strong leadership within cooperatives directly correlates with SMC adoption success.
- **Multi-Stakeholder Involvement is Key:** Effective implementation requires coordinated action from cooperatives, government agencies, development partners, and the private sector.
- **Scalable Business Model Elements:** A cooperative-led, service-fee-based model is viable. Key elements include value proposition, revenue generation via service fees, strategic partnerships, and sustainability through stakeholder alignment.

5.2 Conclusions (Addressing Research Questions)

Research Question 1: How do current milk handling practices contribute to spoilage, and what is the potential impact of solar milk cooling at the farm level?

Conclusion: Poor handling practices—particularly the lack of cooling—lead to spoilage of up to 30% during hot seasons. SMC has the potential to reduce spoilage to near zero, doubling the volume of sellable milk and increasing household dairy income by 20–30%.

Research Question 2: What are the key barriers and enablers for adopting solar milk cooling systems in off-grid rural dairy communities?

Conclusion: Key barriers include high capital cost, lack of access to finance, technical service gaps, and limited awareness. Enablers include cooperative strength, leadership, financing options, and external support.

Research Question 3: How does leadership and stakeholder involvement influence the adoption and scaling of solar milk cooling systems in rural Ethiopia?

Conclusion: Adoption success is heavily influenced by strong local leadership and multi-stakeholder collaboration. Champions who bridge technical, financial, and community engagement are key to scale.

Research Question 4: What scalable and sustainable business model can be developed for implementing solar milk cooling systems in Ethiopia’s dairy sector?

Conclusion: A cooperative-centered, service-based model—with external technical and financial support—emerges as a viable path for scale. It integrates revenue from cooling fees and leverages partnerships for long-term viability.

5.3 Recommendations

5.3.1 For Policy Makers and Government Agencies

- Integrate SMC into national dairy/energy strategies.
- Provide subsidies and low-interest loans for SMC investment.
- Promote enabling regulations and quality standards.
- Strengthen extension services to promote SMC awareness.
- Catalyze public-private partnerships for pilot implementation.

5.3.2 For Development Partners and NGOs

- Implement well-monitored pilot projects across varied regions.
- Co-create financial tools like credit guarantees and blended finance.
- Train local technicians and cooperatives in SMC maintenance.
- Run awareness campaigns and farmer exchange programs.
- Invest in monitoring, evaluation, and research partnerships.

5.3.3 For Dairy Cooperatives and Farmers

- Form groups to co-invest in SMC and share costs.
- Implement service fee systems (e.g., 1–4 Birr/L) for sustainability.
- Train cooperative members on cooler operations and cleaning.
- Engage members regularly and foster internal leadership.
- Explore partnerships for technical, financial, or market support.

5.3.4 For Private Sector (Entrepreneurs, Equipment Suppliers, Financial Institutions)

- Design SMC products suited for rural off-grid use.
- Offer SMC as a service—where farmers pay per use.
- Create dairy-focused loan products for cooperatives.
- Engage in CSR or PPPs to support pilot scale-ups.

5.4 Proposed Business Model Framework for Scalable SMC

Using the Business Model Canvas (BMC), a scalable SMC model features:

- **Customer Segments:** Cooperatives and member farmers.
- **Value Proposition:** Reduce spoilage, increase farmer income.
- **Revenue Streams:** Cooling service fees or premium milk prices.
- **Key Partnerships:** Equipment suppliers, MFIs, government agencies.
- **Channels:** Cooperative-based operations and extension networks.
- **Cost Structure:** Capital equipment, training, maintenance.
- **Key Resources:** Solar cooling systems, trained personnel.
- **Customer Relationships:** Education, technical support, transparency.
- **Activities:** Milk cooling, maintenance, fee collection, training.

This model is modular, adaptable, and scalable across dairy zones.

5.5 Limitations of the Study

- **Sample Size and Scope:** Concentrated around Denkaka; may not represent all regions or dairy systems.
- **Self-reported Data Bias:** Relies on participant recall and perception.
- **Cross-Sectional Design:** No long-term impact tracking.
- **Lack of Financial Modeling:** No detailed ROI or cost-benefit calculations.
- **Limited Social/Gender Analysis:** Cultural and gender dynamics were not deeply explored.

5.6 Suggestions for Future Research

- **Longitudinal Impact Studies** to track real-world SMC performance.
- **Economic Feasibility Analysis** including ROI, payback period, and pricing models.

- **Technical Comparisons** of solar cooling technologies in varied contexts.
- **Behavioral Studies** exploring gender roles, norms, and barriers.
- **Policy and Market Research** to inform government and industry.
- **Comparative Case Studies** from India, Kenya, Uganda for benchmarking.

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APPENDIX A: Quantitative Survey Questionnaire

ADDIS ABABA UNIVERSITY

SCHOOL OF COMMERCE

BUSINESS LEADERSHIP MASTERS PROGRAM

Questionnaire to be filled by Smallholder Dairy Farmers and Cooperative Members

Research Topic: Scalable Business Model for Solar Milk Cooling in Rural Ethiopia: The Case of Denkaka Cooperative

Purpose: This questionnaire aims to collect data to assess milk handling practices, cooling challenges, and readiness to adopt solar milk cooling (SMC) systems in rural Ethiopia.

• Name: Lijalem Eshetu

• Address: Addis Ababa, Ethiopia

• Email: lijalemeshetu@gmail.com

Dear Respondents,

First and foremost, I would like to express my gratitude for your willingness to participate in this survey. This questionnaire is part of a research project conducted in partial fulfillment of a master's degree at Addis Ababa University. All responses will be kept confidential and used solely for academic purposes. The survey will take approximately 10–15 minutes to complete. Your honest and thoughtful responses are highly appreciated.

Instructions:

• Do not write your name; participation is voluntary and anonymous.

• For multiple-choice or scale questions, please mark your response clearly.

SECTION 1: Demographic Information

1. What is your age? (Write your age in years): ___________
2. What is your gender? ☐ Male ☐ Female
3. How many years have you been engaged in dairy farming? ___________
4. How many milking cows do you currently own? ___________

5. Do you have access to reliable electricity on your farm?

   ☐ Always ☐ Sometimes ☐ Not reliable ☐ No access

SECTION 2: Milk Cooling Practices

6. What method(s) do you currently use to cool your milk? ☐ Immersion ☐ Ice blocks ☐ None ☐ Other: ____________
7. On a scale of 1 to 5, how satisfied are you with your current cooling method?

1 (Not satisfied)	2	3	4	5 (Very satisfied)

8. Please describe any difficulties you face with cooling or storing milk: ______________________________

SECTION 3: Challenges in Milk Cooling

9. Please rate the following using 1 (Not a challenge) to 5 (Major challenge):

Challenge	Rating (1–5)
Lack of refrigeration infrastructure	
High cost of electricity	______
System maintenance costs	______
Limited financing	______
Lack of technical support	______

10. How often does milk spoil due to poor cooling?

    ☐ Daily ☐ Weekly ☐ Occasionally ☐ Rarely ☐ Never

SECTION 4: Awareness and Perception of Solar Milk Cooling

11. How familiar are you with solar milk cooling?

    ☐ Very ☐ Somewhat ☐ Heard of it ☐ Never

12. Have you ever sold your evening milk? ☐ Yes ☐ No

13. How do you rate solar milk cooling systems? (1 = Very unfavorable, 5 = Very favorable)

1	2	3	4	5

14. Concerns about SMC:

☐ High cost ☐ Maintenance ☐ Lack of expertise ☐ Reliability ☐ Other: __________

15. To what extent do you agree that your cooperative' s leadership effectively communicates the benefits of adopting solar milk cooling systems?:

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

SECTION 5: Willingness to Adopt SMC

16. If SMC became available, how likely are you to adopt it? (1 = Not likely, 5 = Very likely)

1	2	3	4	5

17. What factors influence your decision? (Choose up to 3):

☐ Cost ☐ Financing ☐ Reliability ☐ Maintenance ☐ Training ☐ Success stories

18. If a service fee per liter were required, how much would you be willing to pay? (Please write the amount in ETB or mark "Not willing" if applicable):

____

_____________ETB

☐ Not willing to pay

SECTION 6: Perceived Impact of Solar Milk Cooling

19. By how much do you believe solar milk cooling could increase your income from milk sales?

☐ No increase ☐ 1–10% ☐ 11–20% ☐ 21–30% ☐ More than 30%

20. By how much do you think SMC could reduce milk spoilage?

☐ No reduction ☐ 1–10% ☐ 11–20% ☐ 21–30% ☐ More than 30%

21. Do you think solar milk cooling could help you sell milk at a better price or to better markets?

☐ Yes ☐ No ☐ Not sure

22. Would you recommend the use of solar milk cooling technology to other farmers?

☐ Yes ☐ No ☐ Not sure

SECTION 7: Open-Ended Feedback

23. What kind of support (training, financing, partnerships, etc.) would help you adopt and use a solar milk cooling system?

____

24. Do you have any other comments, concerns, or suggestions about solar milk cooling?

____

APPENDIX B : Qualitative Research Instrument – Interview Guide

This guide is designed for in-depth interviews with business model developers, cooperative leaders, policymakers, and renewable energy experts.

Introduction and Background

Name and position:

1. How long have you been involved with renewable energy or dairy farming projects?
2. What is your role in relation to solar-powered milk cooling?

Understanding of Solar Milk Cooling (SMC)

3. Could you describe the solar milk cooling (SMC) systems you've worked with or have knowledge of?
4. What are the key benefits you've seen for farmers using solar milk cooling?

Business Models and Financial Viability

5. How do you think solar milk cooling can be scaled to a larger number of farmers in rural areas?
6. What business models have worked well for financing and maintaining solar milk cooling systems?
7. Have you encountered financial challenges in implementing these models? If so, what solutions were implemented?

Challenges to Scaling and Expansion

8. From your experience, what are the most significant challenges to scaling solar milk cooling in rural communities?
9. How have these challenges been addressed in existing projects?
10. What role do you think leadership plays in overcoming these challenges?

Stakeholder Engagement and Community Involvement

11. How do you involve the local community in solar milk cooling projects? Are there any examples where community involvement helped a project succeed?
12. What strategies would be effective in increasing local buy-in for SMC systems?

Long-Term Sustainability

13. What needs to happen for solar milk cooling projects to be sustainable in the long term?
14. How can farmers and local communities maintain solar milk cooling systems after initial installation?

Future Prospects

15. What do you believe are the key factors that will drive the success of solar milk cooling in Ethiopia and other similar regions?

APPENDIX C: Business Model Canvas for Scalable Solar Milk Cooling (SMC) Adoption in Rural Ethiopia

This appendix presents the proposed business model for SMC systems in rural Ethiopia, structured using the nine elements of the Business Model Canvas (BMC). It summarizes key strategic and operational elements to guide scalable implementation, based on the findings from this study.

BMC Component	**Proposed SMC Business Model Details**
Customer Segments	- **Primary:** Dairy cooperatives and their member smallholder farmers (who need milk cooling services). - **Secondary:** Dairy processors or collectors (benefiting from higher quantity/quality milk supply). -**Tertiary:** NGOs, government agencies, and microfinance institutions involved in dairy and energy access—potential supporters of scale-up and replication.

Value Propositions	- **Reduced Milk Spoilage:** Preserves evening milk, reducing post-harvest losses to near zero. - **Increased Farmer Income:** Enables sale of additional milk (e.g., +30% volume) leading to higher earnings. - **Quality and Market Access:** Chilled milk meets quality standards, allowing access to formal markets and better prices. - **Convenience & Reliability:** Local cooling service available within the community, powered by renewable energy (no reliance on grid or diesel), ensuring reliable operation even in remote areas. -**Environmental Sustainability**: Uses renewable solar power, reduces dependency on diesel, and aligns with national climate-smart agriculture goals. -**Gender Inclusion Potential**: Improved household dairy income can benefit women, who often handle milk processing and sales in rural households.
Channels	- Cooperative milk collection centers serve as the physical channel where farmers access cooling services. - Extension services and cooperative meetings act as information channels to educate and attract farmers to use the service. - Mobile technology (SMS/phone) can be used for communications (e.g., notifying farmers of cooler availability, maintenance schedules). -NGO and government outreach programs (e.g., extension agents, cooperative federations) may serve as additional awareness and capacity-building channels.

Customer Relationships	- **Membership & Community:** Built on cooperative membership; fosters trust as farmers collectively own or govern the service. - **Service Agreements:** If a third-party operator is involved (cooling-as-a-service), formal agreements ensure service quality (e.g., uptime guarantees) and payment terms. - **Support & Training:** Ongoing support through training sessions, and a feedback mechanism (e.g., cooperative meetings where farmers voice concerns or suggestions about the cooling service). -_**Collective Governance**: Ongoing involvement of cooperative members through democratic decision-making ensures accountability and adaptation.
Key Activities	- **Milk Cooling Operations:** Daily operation of solar milk chilling (receiving milk, cooling, storing, dispensing to buyers). - **Maintenance:** Regular cleaning of equipment, preventive checks, and prompt repairs (possibly under a maintenance contract with the supplier). - **Fee Collection & Finance:** Managing the cooling service fees or subscription payments, keeping financial records, and handling loan repayments if the equipment was financed. - **Outreach & Expansion:** Demonstrating the cooler's benefits to increase user uptake; planning for scaling to additional units or neighboring cooperatives as demand grows. **- Data Monitoring**: Collect and analyze data on spoilage reduction, income gains, and equipment uptime to support impact tracking and business model improvement.

Key Resources	- **Physical:** Solar milk cooling unit(s) (e.g., 100–300L capacity tank, solar PV panels, battery/ice bank as needed), and a sheltered space for installation (at collection center). - **Human:** Trained cooperative staff or local operator to run the cooling service; technicians available for maintenance; cooperative leadership for oversight. **Financial:** Includes **blended financing** (grants + loans), **maintenance reserves**, and digital tools (e.g., mobile-based payment or tracking system if applicable). - **Social:** Cooperative organizational structure and trust among members, which is crucial for collective investment and usage.
Key Partnerships	- **Technology Providers:** Partnership with solar cooling equipment suppliers for installation, training, and after-sales service. - **Financial Partners:** Banks/MFIs for providing loans or lease financing; NGOs/donors for grants or loan guarantees. - **Government Agencies:** Collaborations with agricultural and energy programs for technical advice, potential subsidies, and integration into extension services. - **Dairy Value Chain Actors:** Dairy processors or buyers who might co-invest or support the cooling centers to secure quality milk supply (could provide performance-based incentives for quality milk). **- Academic Institutions**: Collaborate for ongoing research, impact monitoring, and improving the design of business models and technical innovations.

Cost Structure	- **Fixed Costs:** Depreciation or lease payments for the solar cooler equipment; salaries or stipends for any dedicated operator; initial training costs. - **Variable Costs:** Maintenance and repair expenses (cleaning supplies, occasional spare parts, technician fees); administration costs for fee collection (minimal); energy system upkeep (if batteries need replacement after several years). - **Cost Characteristics:** After initial investment, operational costs are relatively low (solar energy has no fuel cost), making the service economically attractive in the long . Emphasis on preventative maintenance is critical to avoid high repair costs.
Revenue Streams	- **Cooling Service Fees:** Small per-liter fee for milk chilled (e.g., 1–4 Birr per liter) collected from farmers or deducted from milk payments. This is the primary revenue stream, designed to cover operating costs and contribute to capital cost recovery. - **Increased Milk Sales:** While not revenue to the service itself, farmers ' ability to sell more milk leads to cooperative-level revenue growth (through higher volumes handled), potentially allowing cooperatives to allocate a portion of additional profits to sustain the cooling service. - **Secondary Revenue (Optional):** If capacity allows, the cooler could serve other nearby cooperatives or traders for a fee. Additionally, some systems might offer ancillary services (for example, solar power for phone charging at the center for a small fee, though this is minor).