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Master Thesis

Microfinance for the Adoption of Modern Agricultural Technologies by Smallholder Farmers: The Case of Solar Irrigation

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Abstract

This research looks into how microfinance can contribute towards increasing the affordability of smallholder farmers to adopt solar irrigation technology. The study first identified the financial barriers that impede the diffusion of solar irrigation systems within the small farms, from multiple perspectives. Then, an investigation on how smallholder farmers are segmented, and the identification of the relevant solar irrigation stakeholders was conducted to determine the applicable microfinancing services. Lastly, an evaluation of the selected microfinancing services was developed through applying the theory of change model and analyzing the drawbacks of microfinance applications, such as the uncertainty of the effectiveness of rural microfinance, the limited compatibility of microfinance in rural environments and the inability of microfinance institutions to fully operationalize in rural environments, due to the lack of adequate infrastructure. The results of the study show that microfinancing services can potentially enhance the rural economic life, contribute towards the financial deepening of the rural areas, and increase the adoption of solar irrigation systems. The study results also reveals that the drawbacks associated with microfinance can be mitigated by focusing on increasing the financial stability of microfinance institutions, expanding the financial access to new clients, and having more governmental support for these institutions to gain legal status and better off infrastructure, such as roads, electricity systems, mobile networks, etc.

Keywords: microfinance, rural development, solar irrigation, smallholder farmers

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List of Abbreviations

BIS	Bank for International Settlement
FAO	Food and Agricultural Organization
GACSA	Global Alliance for Climate Smart Agriculture
GHGs	Greenhouse Gases
GOGLA	Global association for off-grid solar industry
MFI	Microfinance Institution
NFS	Non-financial Services
NGOs	Non-governmental Organizations
PAYGO	Pay As You Go
SDGs	Sustainable Development Goals
SPIS	Solar-Powered Irrigation Systems
ToC	Theory of Change

1. Introduction

1.1. Background

Sustainable agriculture is essential to achieving the United Nations Sustainable Development Goals (SDGs), as it contributes to alleviating poverty as well as ensuring food and livelihood security (Agrawal and Jain, 2016). Currently, agricultural intensification is central due to the need for higher food production to meet with the growing world population. Irrigation is a key player towards intensifying the agricultural output, especially in arid, semi-arid areas and regions severely affected by climate change. Climate change has resulted in variations in the rainfall levels, which negatively affected the agricultural productivity (Agrawal and Jain, 2016). Rainfall variability is one of the main factors that led to the increasing studies on the sustainable use of surface water and groundwater resources for irrigation (Schmitter et al., 2018).

Solar irrigation, is one of the examples of modern agricultural technologies used for increasing output and contributing towards the meta problem of food production. The Global Alliance for Climate Smart Agriculture (GACSA)[1] has defined solar irrigation as a green technological irrigation system that uses solar energy, instead of fossil fuels, for pumping water, resulting in a decrease in the greenhouse gas emissions from irrigated agriculture (Schnetzer & Pluschke, 2017).

After the installation of the first solar pump in the late 1970s, significant advancements have taken place that eliminated the problems which occurred since the technology was discovered (FAO, 2018). Currently solar pumping technology is equipped with electronic systems and intelligent software that increase the power output of the pump, enhance the performance, and optimize the overall efficiency (FAO, 2018).

Despite the maturity of existing technology for solar pumping irrigation, the rate of adoption is not prevalent globally, and in Africa, specifically. According to the Global Association for Off-grid Solar Industry (GOGLA), the potential market of solar water pumps in Sub-Saharan Africa is estimated to be 43 million; however, the addressable market is around 5.6 million (GOGLA, 2020). The estimation of the potential market is based on the approximate number of farmers who do not have access to electricity grid. This reflects an affordability of 13% of the potential market, which is estimated from the number of farmers

[1] GACSA is a facilitation unit hosted by the FAO (Food and Agricultural Organization)

who could afford buying an average solar water pump size of 220-watt, assuming a price of US$ 650 (Nathan & Scobell, 2020). All these numbers are estimates provided by GOGLA; however, they still give a sense of low adoption and affordability of solar water pumps by the farmers. The low affordability percentage depends on several factors, and this research aims to focus on one of them, namely the access to finance by smallholder farmers. Based on the 2003 World Bank Rural Development Strategy definition, smallholder farmers are defined to be working in smallholdings "with a low asset base and operating in less than 2 hectares of cropland". Murphy adds to this definition by pointing out that smallholder farmers are "characterized by marginalization, in terms of accessibility, resources, information, technology, capital and assets…" (Murphy, 2012, p.3). Low access to finance is one of the barriers, faced by smallholder farmers, that impedes the transition in irrigation technology. Hence, credit has been put forward as a tool for more agricultural development, at which solar irrigation is one of the technologies that contribute to this development (Ajah et al., 2018).

1.2. Problem Statement

Many factors influence the diffusion and sustainability of solar water pumps. Sustainable development has environmental, economic and social dimensions (Brundtland, 1987). This research looks into the economic dimension, with a close focus on affordability and the financial aspect related to solar irrigation, as one of the examples of modern agricultural technologies. The motivation behind the choice of the "economic dimension" is the low affordability of smallholder farmers to adopt modern agricultural technologies that could possibly increase their overall output and productivity. The motivation is also directed towards solar irrigation specifically because solar water pumps are characterized by low operational and maintenance costs and long lifetime. Additionally, solar water pumps reduce the irrigation carbon footprint; contrary to the fuel-powered irrigation whose fuel combustion results in the emission of Greenhouse Gases (GHGs), contributing towards the global warming (Chazarra-Zapata et al., 2020; Adhikari et al., 2019). All these characteristics could possibly increase the potential of solar-powered pumps for agricultural irrigation over fuel-powered ones, if suitable financing mechanisms are set in place (Agrawal & Jain, 2019).

Regarding the affordability and the financial aspect, the high upfront cost of solar water pumps is one of the barriers that disincentivize farmers from adopting the technology. The rationale behind this is the unavailability of cash and the farmers' low-income levels in poor and developing countries. In addition to the high upfront costs, little to no access to formal credit is one of the main reasons for the low affordability of smallholder farmers to adopt more

technological and productive types of irrigation, such as solar irrigation (Mugenzi, 2014). The reasons attributed to the low credit accessibility of farmers include high transactions costs, lack of collateral, high interest rate and low pay back time (Mugenzi, 2014). Information asymmetry is another reason that leads to low credit accessibility, especially when it comes to 'new' technologies, like solar water pumps (Agrawal & Jain, 2018). All the reasons and barriers stated above are the cornerstone to the initiation of Microfinance Institutions (MFI) that implement microfinancing services to increase farmers' credit accessibility and to enhance their livelihood by providing them with funding that could improve their agricultural productivity. Elaboration on MFIs and their roles in sustainability and agricultural contexts are explored in chapter 2.

1.3. Research Objective

The objective of the research is to assess microfinance and its potential impact on alleviating the financial burden on smallholder farmers to transition from conventional irrigation systems, such as mechanical or diesel-powered irrigation, to solar-powered irrigation systems. This assessment is an attempt to explore the potential of microfinance on increasing the affordability and contributing to the adoption of solar-powered irrigation. The objective will be achieved by understanding the financial barriers that are faced by the farmers and evaluating the extent to which microfinance can assist in tackling these barriers. Additionally, the research aims to identify the most applicable microfinancing services that can be provided to farmers in the context of solar irrigation. Lastly, the research will result in recommendations on possible policies that can further enhance the effectiveness of microfinance.

1.4. Research Questions

The main research question of the thesis is:

> To what extent can microfinance enable smallholder farmers to adopt modern technologies for improving agricultural output?

The three research sub-questions of the thesis are:

1. What are the financial barriers that impede the diffusion of solar irrigation among smallholder farmers?
2. What are the existing microfinancing services available to smallholder farmers for agriculture and irrigation?
3. How successful have microfinancing services been in promoting modern agricultural technologies, such as solar irrigation?

1.5. Thesis Outline

The outline of the thesis is as follows: Chapter 2 points to the relevant literature review that serves as an essential background knowledge and the theories needed before conducting the research. The literature review focuses on developing a framework on the three thematic areas at which the three research sub-questions are based on. Chapter 3 explains the research design and the methodology needed to conduct the research. Chapter 4 chapter presents the answers to the research questions. Lastly, Chapter 5 presents a conclusion on the whole study, reflection on the thesis process, policy recommendations and future research directions.

2. Literature Review

This chapter is divided into three sections. The first one presents the framework at which the financial barriers that affect the diffusion of solar irrigation is based on. The second section presents the definition of microfinance and the application of this mechanism in sustainability context and agricultural context. Additionally, it draws attention on the target audience of microfinance, through understanding the segmentation of smallholder farmers, and the essence of the application of the stakeholder theory to identify the main actors involved in the solar irrigation technology. Lastly, the third section explains how the Theory of Change (ToC) can be used to trace the success of microfinance, its applicability and its key elements.

2.1. Financial Barriers that Affect the Diffusion of Solar Irrigation

One of the key challenges for the adoption of solar irrigation technology in small farms, defined as those with cropland less than two hectares (Thapa and Gaiha, 2014), is the low affordability of smallholder farmers (FAO, 2018). The low affordability is originated from the financial mismatch between agricultural credit demand and supply, as well as from the solar irrigation technology itself (Capacio et al., 2018). The agricultural credit demand side refers to the smallholders' capacity and willingness to access and use the offered financial services. Effective demand typically takes place when the smallholder farmers have the essential financial literacy to know about the offered financial services and programmes. Additionally, smallholder farmers need collateral terms and documentary requirements for the financial services that would match their cash flow and needs (Capacio et al., 2018). The agricultural credit supply refers to the financial service providers' ability and willingness to deliver the required financial products or services. Effective supply typically takes place when the agricultural lending risks are minimized and when the costs associated with lending are reduced (Capacio et al., 2018). This would be achieved through having loan officers specialized in agriculture, who would in turn understand the financial needs of the smallholder farmers and the financial services applicable to them. Lastly, solar irrigation technology in itself represents a financial barrier for both the smallholder farmers and financial institutions. Due to a lack of knowledge about a new technology, financial institutions often view solar irrigation to be high risk, reducing the chances of giving credit to smallholder farmers (Agrawal & Jain, 2018). Additionally, solar irrigation is characterized by high upfront cost, deterring smallholder farmers from investing in the technology due to lack of capital (Diop et al., 2020). Lastly, the presence of taxes on the imported solar irrigation components and the lack of standardization increases the overall cost of the technology and reduces the farmer's affordability (FAO, 2018).

More elaboration on the affordability problems is provided in section 4.1. Figure 1 represents the financial barriers from both sides; demand side, referring to smallholder farmers and supply side, referring to financial institutions.

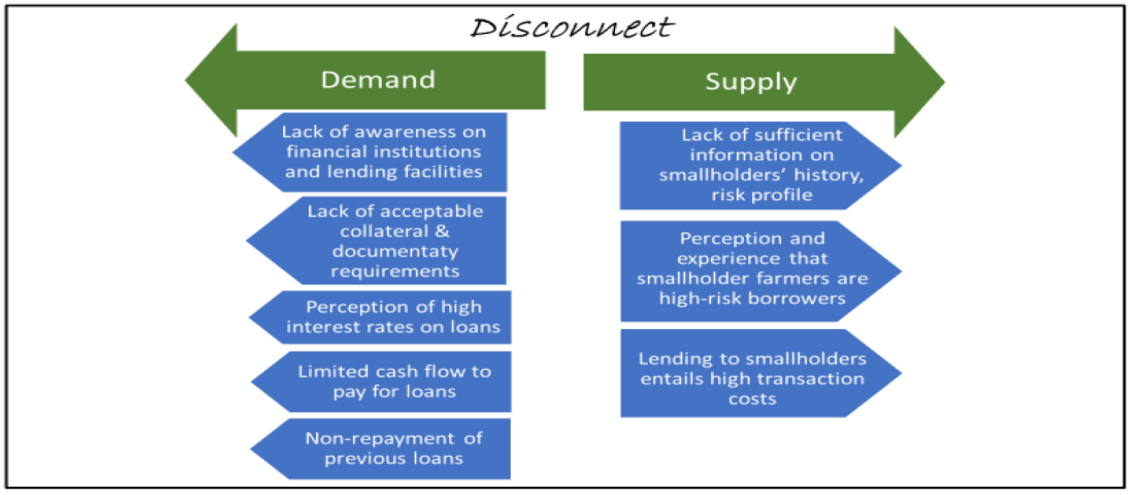

Figure 1: Demand and supply mismatch of financial services (Capacio et al., 2018).

Based on the aforementioned review, the demand side, (i.e., smallholder farmers), the supply side, (i.e., financial institutions) and the technology side, (i.e., solar irrigation) contribute to the creation of financial barriers that would in turn reduce the diffusion rate of the technology within small farms. Some of the financial barriers included in each of the three above-mentioned perspectives are directly or indirectly related to each other. Figure 2 demonstrates the relationship between the three different perspectives, at which you can find that each barrier set has a link with two other barrier sets, reflecting the strong connection between the financial factors impeding the adoption of modern agricultural technologies, such as solar irrigation. Detailed elaboration on each of these perspectives is provided in section 4.1.

Figure 2: Financial barriers to solar irrigation from different perspectives

2.2. Definition of Microfinance

Despite the fact that many research papers and publications have been produced about microfinance, there is no internationally agreed-upon definition. Microfinance is the financing of impoverished individuals, namely people without a bank account, who as a consequence have no access to financial institutions, due to lack of money and social, cultural, and gender obstacles (Mermod, 2013). Currently, microfinance is an essential financial tool, especially for developing countries, for the provision of microfinancing services that assist low-income clients overcome some of the financial barriers that they face (Mermod, 2013).

2.2.1. Microfinance in the Sustainability Context

In the context of sustainability, microfinance plays an important role in financing green projects for the poor people who cannot afford the adoption of clean technologies. This is usually the case with solar irrigation, at which smallholder farmers find as a costly option for irrigating their lands, due to the high upfront cost needed for installation (Alves et al., 2014). Financing green projects is referred to as "Green finance", which is a phenomenon that blends the area of finance with environmentally responsible behavior. Different stakeholders are involved in the accomplishment of this behavior, including individuals, business customers, manufacturers, investors and financial lenders (Wang & Zhi, 2016). The public sector in most countries, especially in developing ones, cannot afford to fill the large investment gap that is existent in green energy projects, and the private sector has shown little interest in that as is well, due to the low rate of return and the associated risks (Sachs et al., 2019). Hence, there is an urgent need to scale up the financing needed for investments that provide environmental benefits, which would contribute to achieving the SDGs. There are various instruments that can be used to scale up the financing for green projects, "such as green bonds, green banks, carbon market instruments, fiscal policy, green central banking, fintech, community-based green funds, etc." (Sachs et al., 2019, p.1). All of these instruments fall under the same umbrella of green finance that aims towards increasing the investments in sustainable projects (Sachs et al., 2019). Microfinance directed towards poor community segments for enhancing their livelihood and sustainability, such as solar irrigation, can fall under green financing, as well.

2.2.2. Microfinance in the Agricultural Context

Microfinance plays an essential role in agriculture and more specifically to smallholder farmers. Since this thesis focuses on microfinance for the adoption of solar irrigation technologies to smallholder farmers, a distinction between the following terminologies should

be set clear: rural finance, agricultural finance and microfinance. Rural finance refers to the financial services provided to people living in rural areas, regardless of their income levels (Pearce, 2003). Agricultural finance refers to the financial services allocated only to agricultural-related activities, such as supply, production, distribution, etc. Agricultural finance is a subset of rural finance (Pearce, 2003). Lastly, microfinance is the provision of the financial services to the poor people (Pearce, 2003). The area of interest that this thesis tackles is the intersection area, shown in figure 3, between microfinance and agricultural finance. It includes the provision of the financial services, specified to the poor people living in rural areas and working in the agricultural sector (Pearce, 2003). In this area, there are various microfinancing services that are to be demonstrated in section 4.2. Not all these microfinancing services are applicable to all types of smallholder farmers. Accordingly, studying the segmentation of smallholder farmers is essential to be conducted to determine the microfinance target audience and to find the most applicable financing services for them.

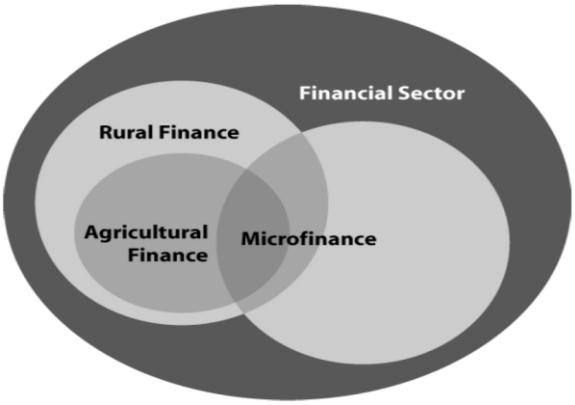

Figure 3: Distinction between rural, agricultural and microfinance (Pearce, 2003)

2.2.3. Segmentation of Smallholder Farmers

Smallholder farmers are categorized into three main segmentations based on commercialization: subsistence farmers, commercial farmers, and semi commercial farmers. The basis of the segmentation has to do with the loan sizes and the farmer's cash flow analysis (Physik, 2018). However, smallholder farmers are diverse in terms of gender mix, land size, crop choice, market engagement, agricultural technology accessibility, and financial accessibility (Christen & Anderson, 2013). Assessing the three segmentations of smallholder farmers in terms of these six factors would give a clear distinction between each segment and further assist the research to determine the compatibility of the microfinancing services with the farming segmentations.

Subsistence farmers typically do not establish any commercial links for their products, and they only use them for their own household consumption. Most of the people working in this segment are women; that is why credit discrimination, particularly for women, and inaccessibility to formal financial institutions are prevalent (Christen & Anderson, 2013). The land sizes among subsistence farmers vary significantly from one country to the other, depending on the soil quality and water accessibility. Furthermore, the ownership of agricultural land is fragmented, especially for subsistence farmers living in poor developing countries. This land fragmentation is the reason behind the high number of subsistence smallholder farmers, as some of them do not own their lands due to governmental fears of transferring these lands into urban areas. Accordingly, some of the subsistence farmers, living especially in low-income countries, have their lands under usufruct agreements[2], limiting their legal and financial rights. In terms of crop mix, most of the crops cultivated by subsistence farmers are staple crops[3] and no cash crops are cultivated, and what they produce is for their own consumption.

All the above-mentioned factors, namely the large number of women as subsistence farmers, lack of land ownership and the inability to cultivate to cash crops, expose the farmers from this segment to vulnerability in terms of market engagement, agricultural technology accessibility, and financial accessibility (Christen & Anderson, 2013). These three factors are interrelated to each other. If small farmers are incapable to engage with the market, it would contribute towards low-income levels, which would in turn decrease the chance of taking loans from formal financial institutions to invest in modern agricultural technologies.

On the other hand, commercial and semi-commercial farmers are considered to be better off than the subsistence farmers. Commercial farmers are characterized by their operations in a tight value chain, which gives them the capability to engage in the market, cultivate higher-value crops and own larger land areas, at least more than two hectares (Physik, 2018). Given all these characteristics and the low participation by women in agricultural commercialization, commercial farmers have high financial accessibility due to the existence of valuable collateral, which would assist them to adopt modern agricultural technologies, such as solar irrigation. On the contrary, semi-commercial farmers are financially on a higher level

[2] Usufruct agreement is the "legal right accorded to a person or party that confers the temporary right to use and derive income or benefit from someone else's property" (Kenton, 2021).

[3] "A staple crop, by definition, dominates a major part of our diet and supplies a major proportion of our energy and nutrient needs" (Kilian, 2012, P.1)

in comparison to subsistence farmers and on a lower level in comparison to commercial farmers. They are characterized by their operations in a loose value chain, relatively lower dependency on women compared to subsistence farmers and land sizes that vary between one and two hectares (Christen & Anderson, 2013). Most of lands cultivated by semi-commercial farmers produce staple crops, at which their surplus is mostly sold in local markets (Christen & Anderson, 2013). Therefore, semi-commercial farmers are considered to be engaged in the market, but in a limited manner; this would accordingly limit their financial accessibility and their adoption of modern agricultural technologies.

Based on the above segmentation of smallholder farmers, this research focuses only on the commercial and semi-commercial farmers as the target group that would potentially make use of the microfinancing services. The provision of finance to subsistence farmers has compounded challenges, such as the inexistence of marketable crop surpluses (Physik, 2018). Subsistence farmers are the poorest segment of smallholder farmers, and they are the least likely to benefit from microfinance (Mecha, 2017). This problem can be attributed to the following reasons: 1) the eligibility standards of the MFIs may not consider the poorest of the poor, as ones of the possible clients for the MFIs, 2) microfinancing services may be inherently incapable of assisting the poorest, and 3) MFIs may not be successful in reaching out to the poorest segment of the smallholder farmers, due to the segment's lack of participation and self-exclusion (Mecha, 2017).

2.2.4. Stakeholder Theory in Solar Irrigation

In the context of both solar irrigation and microfinance, stakeholder theory is to be used in the thesis, due to its extensive use in strategy development literature (Polonsky, 1995). The essence of this theory is its consideration of a wide range of actors and their influence on the activity of study, i.e., microfinance to smallholder farmers. Accordingly, after the identification of the various types of smallholder farmers and the differences between them, it is essential to investigate the roles of the other actors involved in the solar irrigation value chain. This better identifies where to position MFIs and which actors are essential to these institutions to assist them in offering their microfinancing services to smallholder farmers. While this section looks more into the theory description and the justification of its usage, the application of the theory is demonstrated in section 4.2, with the description of each actor's role and its contribution to the financing aspect of solar irrigation systems.

2.3. Assessing the Success of Microfinance

Tracing the success of the application of microfinance for increasing the adoption of solar irrigation systems in small farms is essential to explain how the intervention, i.e., microfinancing services, could possibly change the lives of the beneficiaries, i.e., smallholder farmers (Weijermars, 2014). This explanation can be retrieved through applying the ToC, as the grounding theory for tracing the success of microfinance in that context. ToC is typically presented in a diagrammatic format, followed by a narrative that describes three main aspects: 1) the problem, 2) the intervention used, i.e., input and 3) the expected results in terms of output, outcome, and impact. The ToC assists in visualizing the causal chains that start after the implementation of the interventions and end at the achievement of the desired long-term goals. Setting out the desired long-term goals and impacts is essential to describe how exactly the interventions will bring about this change. The identification of clear set of assumptions is also significant, as this would represent the "underlying conditions or resources that need to exist for planned change to occur" (RVO, 2018, p.1). The ToC is just an approach for the determination of possible pathways for reaching to the possible desired impacts. However, these impacts may not always be achieved, depending on the conditions under which the interventions operate. Due to the hardship of generalizing conclusions on potential impacts, a validation of the causal chain of the ToC can be applied. These validation studies are specifically important in microfinance field, due to the debate of its mixed outcomes (Weijermars, 2014). Hence, preparation of randomized control trials, having the highest internal validity, or pipeline studies is essential to clear out some uncertainties (Weijermars, 2014).

There are some key elements that should be included in every ToC. Table 1 presents these elements along with a brief description for each one of them.

Table 1: Theory of Change elements and descriptions (The SEEP Network, 2015)

Element	**Description**
Inputs/Interventions/Activities	Actions taken with the aim of solving the problem at hand
Outputs	Direct deliverables of the inputs
Outcomes	The changes that take place after the adoption of the outputs
Impacts	Long-term changes that the inputs work towards accomplishing and they are derived from the accumulation of outcomes

3. Research Design

This section explains how the concepts and the theories demonstrated in chapter two can be operationalized. It starts by introducing the research framework in five steps, followed by explaining the research strategy, data sources and collection methods, data analysis, analytical framework and finally the ethical standards pursued throughout the thesis process.

3.1. Research Framework

This section includes a step-by-step approach to the research objective. The research framework consists of the following steps:

Step 1: Characterizing the objective of the research project.

The specific objectives of the research project are as follows:

1) Understanding the financial barriers that impede the diffusion of solar irrigation.
2) Identifying the existing microfinancing services appropriate for agriculture and understanding their dynamics.
3) Analyzing to what extent existing microfinancing services can overcome the financial barriers impeding the adoption of modern agricultural technology, with focus on solar irrigation transition, as a 'test case' technology.
4) Drawing conclusion and recommendations on how to further promote MFIs and increase their effectiveness.

Step 2: Determining the research object.

The research is focused on the financing element for the adoption of solar-powered irrigation as an example of technological upgrading to promote farm output. Hence, the research object is microfinance provided to commercial and semi-commercial smallholder farmers.

Step 3: Establishing the nature of the research perspective

The research is assessing the potential of microfinance in addressing the financial barriers that the smallholder farmers face in the transition process to solar-powered irrigation. The assessment is based on the evaluation of the existing microfinancing services through looking at their strengths and imperfections based on literature surveys, as well as, by interviewing experts. The study then gives recommendations to commercial and semi-commercial smallholder farmers on the most applicable microfinancing services that could be

utilized to adopt solar-powered irrigation. In addition to that, recommendations are also given to MFIs on how to solve the imperfections existent in microfinancing services to increase their effectiveness and adoption by smallholder farmers. Accordingly, the study is practice-oriented research with a combination of problem analyzing and diagnostic research. The research perspective is a conceptual model, linking the financial barriers, microfinancing services and the evaluation of microfinance in agricultural context all together to contribute towards effective transition of smallholder farmers towards solar irrigation.

Step 4: Making a schematic representation of the research framework

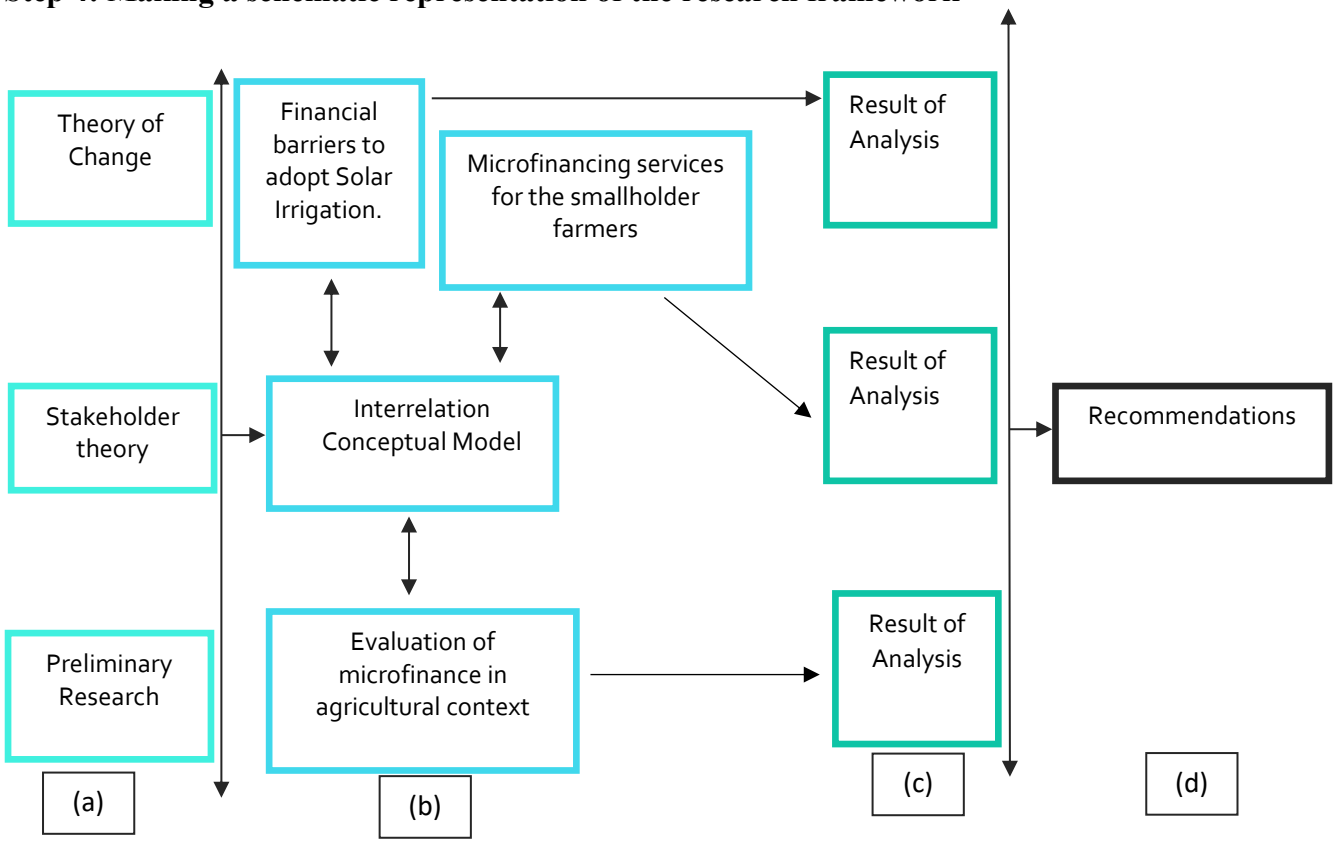

Figure 4: Schematic diagram for the research framework

Step 5: Formulating the research framework in form of arguments.

a) Literature reviewing on theory of change and stakeholder theory. In addition to that, preliminary research is conducted through interviewing experts related to the study field.
b) Dealing with the literature review and the preliminary research as the basis at which the research object will be assessed
c) Dealing with the results of the analysis as the basis for recommendations.

d) Recommendations on the best microfinancing services and the policies that could alleviate the barriers related to the transition of smallholder farmers towards solar irrigation.

3.2. Research Strategy

Based on the objectives and questions demonstrated above, the research strategy focuses on the depth rather than the breadth of microfinance. This is tackled through conducting an in-depth examination of the effect of microfinance on the adoption of solar irrigation, as an example of modern technologies used for improving agricultural output. The in-depth examination is based on conducting desk research and interviews on the financial barriers experienced by smallholder farmers, as well as the microfinancing services related to agriculture. The desk research includes literature survey and secondary research, of which most of the data is empirical, that is mainly compiled by other researchers. The research is grounded theoretically, through applying the ToC and the stakeholder theory. The ToC is needed to evaluate the effectiveness of microfinance towards the adoption of modern agricultural technologies. The stakeholder theory is needed to determine the actors related to solar irrigation technology value chain and their influence on financing the technology.

3.2.1. Research Unit

Microfinancing services offered by MFIs are the selected research unit of the thesis. They are utilized to overcome the affordability problems of smallholder farmers to adopt modern agricultural technologies, such as solar irrigation.

3.2.2. Research Boundary

In order to finalize the thesis research in a timely manner, there are some boundaries that are used in this research to guarantee its completion and feasibility.

The boundaries used in this research are:

1) Focusing on the financial aspect, as the impeding factor towards the implementation of modern agricultural technologies, such as solar irrigation.
2) Focusing on solar irrigation, as an example of modern agricultural technologies.
3) Focusing on MFIs and their role towards providing microfinancing services to smallholder farmers.

3.3. Data Sources and Collection Methods

The data and information needed to answer each research sub-question were collected via documents (academic papers and grey literature) and semi-structured interviews. The interviews were conducted with experts from international organizations concerned with solar irrigation, civil society, and banking sector. The interview questions for this research were divided into two categories. The first category was mainly directed towards experts working in Regional and International organizations concerned with renewable energy. The experts who were interviewed in this category work at the FAO, African Union Commission and the World Food Programme. They gave the research valuable insights about solar irrigation and the barriers that impede its uptake in small farms. The second category was mainly directed towards experts working in financing organizations (both civil society and banking sector). The experts who were interviewed in this category work at Oxfam Novib and Rabobank. They gave the research valuable insights about financing microprojects, the risks that surround microfinance and the relevant financial services applicable to smallholder farmers. Getting first-hand-data from these organizations assisted the study in assessing the impact of microfinancing services that are provided to farmers on the adoption of new agricultural technologies, such as solar irrigation.

Table 2 lists the research participants and their respective organizations[4]

Table 2: Research participants

Interview number	Name of the participant	Organization
01	Mr. Assem Korayem	World Food Programme
02	Dr. Manas Puri	Food and Agricultural Organization (FAO)
03	Ms. Tamara Campero	Oxfam Novib
04	Mr. Peter kinuthia	African Union Commission
05	Mr. Tom Gruintjes	Rabobank

[4] The sixth research participant provided me with some reports that were valuable to the research

Table 3: Data sources and collection methods

Research Question	Data/information required to answer the question	Sources of data	Accessing Data
What are the financial barriers that impede the diffusion of solar irrigation among smallholder farmers?	- Financial barriers from solar irrigation perspective	Secondary Data Documents [5]	Content Analysis
		Primary Data Semi-structured interviews with solar irrigation experts	Questioning Virtual interviews
	- Financial barriers from smallholder farmers' perspective	Secondary Data Documents	Content Analysis
		Primary Data Semi-structured interviews with microfinancing experts and solar irrigation experts	Questioning Virtual interviews
	- Financial barriers from financial institutions' perspective	Secondary Data Documents	Content Analysis
		Primary Data Semi-structured interviews with microfinancing experts	Questioning Virtual interviews
What are the existing financing services applicable to agriculture and irrigation to smallholder farmers?	- Solar irrigation stakeholders	Secondary Data Documents	Content Analysis
	- Microfinancing services applicable to both smallholder farmers and solar irrigation systems	Secondary Data Documents	Content Analysis
		Primary Data Semi-structured interviews with microfinancing experts	Questioning Virtual interviews
How successful have microfinancing services been in promoting modern agricultural technologies, such as solar irrigation?	- Impacts and drawbacks of the provision of microfinance to smallholder farmers	Secondary Data Documents	Content Analysis
		Primary Data Semi-structured interviews with microfinancing experts	Questioning Virtual interviews

[5] Documents refer to academic papers, reports, grey literature. The choice of the type of the documents depends on the availability of resources and how best they can serve the research.

3.4. Data Analysis

3.4.1. Method of Analyzing Data

Qualitative data analysis was conducted throughout the research process. This took place by first analyzing the financial barriers that impede smallholder farmers from adopting modern agricultural technology. This was then complemented by applying the stakeholder theory to analyze the stakeholders along the value chain of the solar irrigation systems. Moreover, the microfinancing services that could mitigate the financial barriers were analyzed qualitatively and the effectiveness of these services for the smallholder farmers were evaluated through applying the ToC and through investigating the current drawbacks of microfinance in the agricultural context. The analysis was mainly based on secondary research and by getting insights from experts working in the microfinance and developmental fields. Lastly, qualitative analysis of the relevant policies for rural microfinance was conducted to serve as recommendations on how to strengthen the governance system of the MFIs that serve small agricultural farms.

Table 4: Data analysis

Data/Information Required to Answer the Question	Method of Analysis
- Financial barriers from solar irrigation perspective	Qualitative: investigating the economic dimension of solar irrigation, from which financial challenges will be retrieved.
- Financial barriers from smallholder farmers' perspective	Qualitative: investigating the factors that exclude smallholder farmers from accessing financial services.
- Financial barriers from financial institutions' perspective	Qualitative: investigating the risks that demotivate financial institutions or farmers to invest in solar irrigation.
- Solar irrigation stakeholders	Qualitative: Applying the stakeholder theory to have an overview of the relevant stakeholders and how can they contribute towards enhancing the affordability.
- Applicable microfinancing services	Qualitative: as inputs to the ToC model.
- Impacts and drawbacks of the provision of financial services on smallholder farmers	Qualitative: evaluation of microfinance in the agricultural context by applying the ToC, and the investigation of drawbacks to provide recommendations for improvement.

3.4.2. Data Validation

Throughout the research process, data was validated through using multiple sources and through cross checking the information obtained to ensure the validity of the results. It is also essential to avoid research bias, hence triangulation technique was used to ensure the validity of the qualitative data analysis. This was accomplished by using various methods and sources to obtain the needed data for the research. The data sources that were used mainly retrieved from literature and semi-structured interviews.

3.4.3. Analytical Framework

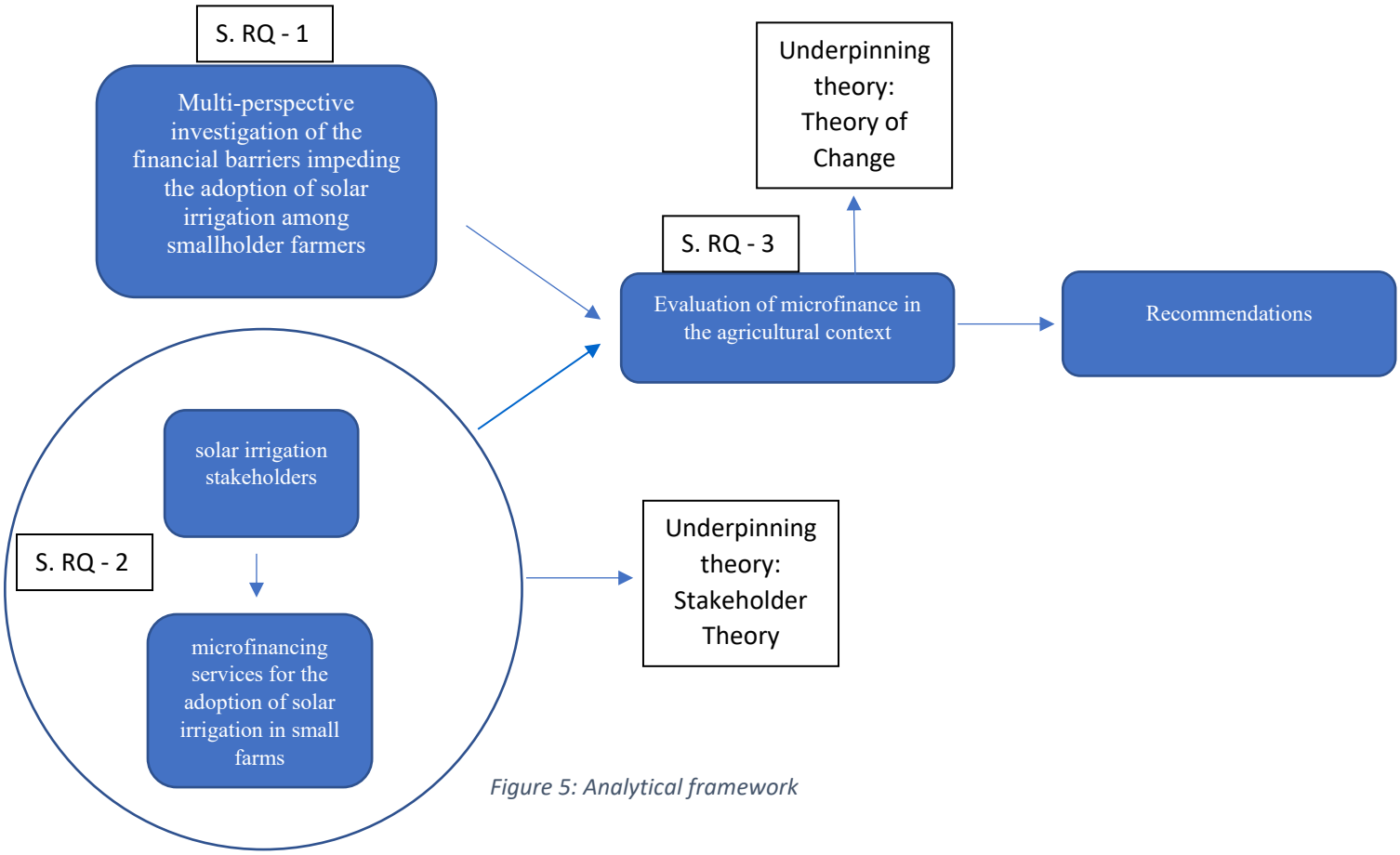

Figure 5: Analytical framework

Step 1: The financial barriers that impede the adoption of solar irrigation in small farms are investigated from multiple perspectives. This investigation answers the first research sub-question and is considered as an extensive elaboration of the problem statement, that is to be followed by a solution and its evaluation in sub-questions two and three, respectively.

Step 2: This step is divided into 2 parts; the first part investigates the solar irrigation stakeholders. The underpinning theory used in this step is the "Stakeholder theory" to analyze the actors and their roles in the value chain. The second part investigates the relevant

microfinancing services aimed towards alleviating the barriers demonstrated in the first step. Understanding the stakeholders is a prerequisite for the second part, to have a better overview on the actors that could be involved in the microfinancing services.

Step 3: The microfinancing services demonstrated in step 2 are evaluated by applying the ToC model in order to trace the interventions and their resultant outputs, outcomes, and impacts. The ToC is a substitute to the conduction of experimental and observational methods that involve several complications in their execution. The methods' complications will be further discussed, in section 4.3.2. among the drawbacks of microfinance in the agricultural context.

3.5. Ethical Statement

The thesis research follows and respects the academic ethical standards stated by University of Twente. The research also guarantees having a transparent, honest and an independent attitude throughout the whole writing process. The thesis includes semi-structured interviews from some experts in the field. Before conducting the interview, an informed consent form, included in the appendix, is used to safeguard the rights of the interviewee.

4. Results

This chapter is divided into three sections. The first section investigates the financial barriers that impede the adoption of solar irrigation technology among smallholder farmers. The second section identifies the stakeholders relevant to solar irrigation systems and the microfinancing services that are offered by MFIs. Lastly, the third section evaluates microfinance through applying the ToC and identifying the drawbacks of microfinance in the agricultural context.

4.1. Financial Barriers for the Adoption of Solar Irrigation by Smallholder Farmers

Adoption of modern agricultural technologies, including solar-powered irrigation is subjected to various financial barriers. As explained in section 2.1, the financial barriers are to be looked at from three different perspectives: 1) farmers' perspective, 2) solar irrigation technology perspective and 3) financial institutions' perspective.

4.1.1. Financial Barriers from the Farmers' Perspective

This sub-section investigates a range of intrinsic factors that make the smallholder farmers incapable of adopting modern agricultural technologies, such as solar irrigation. These intrinsic factors are based on the farmers' perspectives and hence the following is elaborated on in this section: financial literacy, farmers' low income, gender-based credit discrimination and farmers' risk perception.

4.1.1.1. Financial literacy

Financial inclusion of the vulnerable communities aims to enhance the lives of the poor people, including the smallholder farmers, to have the basic financial services such as savings, payments, and credit. The provision of the financial services to smallholder farmers is not in itself the only factor responsible for the financial inclusion; however, the extent of the literacy that these farmers have is an essential element towards achieving successful inclusion strategy. Financial illiteracy, defined as the lack of the capacity to comprehend and use a variety of financial concepts and abilities, such as personal financial management, budgeting, and investing, is one of the main reasons behind the farmers' lack of engagement towards the current available financial instruments (Fernando, 2021). Most of these instruments play a role in the farmers' growth, as they aim towards increasing the farming assets and crop yields, leading to higher agricultural productivity. More information about the financial instruments catered to smallholder farmers is described in section 4.2.

Financial illiteracy is widespread and could be prevalent among societies from low-tiered income levels, due to their low educational standards (Fatih et al., 2017). The illiteracy about the existing financial services leads the smallholder farmers to be vulnerable to misjudgments when it comes to financial decisions. These misjudgments can range from "borrowing at high interest rates, acquiring fewer assets at times that could have high rate of return on their agricultural investment, accumulating excessive debt, not taking advantage of financial innovations and depending on family and not experts on the financial advice" (Aggarwal et al., 2014, p.37). All these problems are just some examples of the wrong decisions that smallholder farmers typically take due to their ignorance about the correct financial course of actions. Hence, financial literacy is an essential skill, with which smallholder farmers need to be equipped with to be able to take sound decisions that could reflect positively on their agricultural investment.

4.1.1.2. Farmers' low income

One of the financial barriers that restrict smallholder farmers from investing in modern agricultural technologies is the low-income levels and the acute rural poverty that led to struggles in the fulfillment of the farmers' basic needs. According to the FAO, the capital to labor ratios in small farms is typically low, as the farmers rely on labor instead of capital to produce food, which results from the low affordability of smallholders to invest in modern assets that have high upfront costs (FAO, 2015). This information can explain the low adoption rate of (solar) irrigation in the poor farms, although irrigation is a "major determinant of land productivity" and can be considered as one of the most significant productive assets in agricultural farms (FAO, 2015).

4.1.1.3. Credit discrimination between men and women

Gender gap in access to finance is one of the barriers that women in the farming sector get exposed to. It restricts them from improving their agricultural output, due to the lack of women's accessibility to financial institutions which could support smallholder farmers to invest in modern agricultural technologies. This barrier was mentioned by three key informants from the agricultural sector during the interviews for this study as an essential factor towards the lack of financial inclusion (interviewees 2, 3 and 4). The three interviewees emphasized that "land ownership and lack of collateral" are the main constraints that contribute to widening the gender gap in financial inclusion. The rationale behind this is that formal financial institutions see women who do not have collateral (acceptable assets) or land ownership contracts, as

unattractive clients; hence, the loan rejection is mostly the norm in these circumstances (interviewees 1, 3 and 4). However, more reasons, other than the "land ownership and lack of collateral" could contribute towards increasing the inequality between men and women in accessing financial services. Socio-cultural norms act as a significant contributor that negatively impact women's accessibility to finance (FAO, 2020). This is attributed to the traditional cultures of rural women who invest a lot of time in household tasks, leading to time and mobility constraints. This would reduce the women's interaction with financial institutions in a disproportionate level compared to men (FAO, 2020). Another factor that reduces women's interaction is that any official (ministry or from financial organization) who comes to the village tends to be a man and they only speak to men in the village. Sometimes this is a cultural tradition about non-family men entering the household space of women. It also can be due to the official's poor understanding of rural lives and not recognizing women as farmers. In addition to time and mobility constraints, sometimes being the main responsible for the household tasks demotivates women to invest in education. This is a supplementary factor to the existing gender gap in education, leading to challenges in understanding the basic financial terms, low money management skills and hence, high level of financial illiteracy leading to lower creditworthiness of women (FAO, 2020).

4.1.1.4. Farmers' risk perception

Understanding the smallholder farmers' risk perception is essential for the relevant financial services that could be provided to smallholder farmers to adopt solar irrigation technology. Not only does the knowledge of farmers' perception about risks help them to better manage their farms, but it also assists financial institutions to provide better innovative financial services/products that take into account the needs of the farmers, as well as their fears towards investments in capital-intensive assets (Sulewski et al., 2020). Farmers and especially the smallholder farmers are characterized by high levels of risk aversion, which is a typical risk attitude identified in several agro-economic studies (Ullah et al., 2015; Iyer et al., 2020; Holt and Laury, 2002). Characterizing smallholder farmers with high risk aversion is just a general observation from the literature. The extent of risk aversion may vary from region to region and also depend on other factors, such as income and farm sizes. Nevertheless, risk aversion is one of the financial barriers towards the adoption of modern agricultural technologies. Feder has observed that risk averse farmers are less willing to invest in

agricultural inputs even if these inputs could lead to an increase in the agricultural productivity (Feder, 1980). Connecting all of that together, it is essential to overcome this barrier by accommodating financial services with better risk management tools to motivate farmers to invest in agricultural assets, while taking the farmers' risk perception into consideration. More information about these financial services is explained in section 4.2.

4.1.2. Financial Barriers from the Solar Irrigation Technology Perspective

In order to better visualize the financial barriers in solar irrigation, it is essential to understand the economic feasibility of solar water pumping and how it is compared to conventional irrigation types. With regards to the investment cost, farmers would need to pay higher upfront cost to adopt solar-powered irrigation system than that of the diesel-powered system. The investment cost of the solar-powered irrigation system depends on several factors that are, but not limited to "the required photovoltaic capacity, import taxes for photovoltaic solar energy and related equipment, and the requirements and dimensions of water storage or battery storage facilities" (Diop et al., 2020, p.12). All these factors increase the upfront cost of solar-powered irrigation, in comparison to diesel-powered one. Many developing countries and in Africa specifically, the solar irrigation technology is still coming up and hence the local production of the components does not sufficiently exist (interviewee 2). The insufficient existence of local production forces investors to import the components from other countries which then adds up to the total upfront cost of the irrigation system (interviewee 2). In addition to that, sometimes there are even no proper import guidelines or quality assurances, which would in turn make farmers to lose faith in the technology itself, widening the scope of the problem and impeding the adoption of solar-powered irrigation by small farmers, even more (interviewee 2). Although the upfront cost of solar-powered irrigation is higher than that of traditional irrigation types, using solar water pumps remains an economically feasible and reasonable decision due to its low operational costs (Diop et al., 2020). A study conducted in Iran found that after the operation of 25 years, life cycle costs of the solar pumps remained lower than the traditional pumps by a factor of 1.56 times (Diop et al., 2020). This was also supported by Hossain et al. (2015), who found that the life cycle costs of solar pumps are more economic than diesel-powered pumps after a period of five years or more. Consequently, solar irrigation can be considered as a better alternative in the long term for isolated rural areas. However, still the upfront cost problem needs to be solved using innovative financial schemes

that would provide the farmers with better payment and credit options to motivate them to adopt more sustainable irrigation technologies, such as solar irrigation.

In addition to the high upfront cost barrier of solar irrigation, lack of standardization also represents a financial challenge for effective adoption of solar-powered irrigation (interviewee 2). The interviewee sees that lack of standardization of the solar irrigation components would eliminate the trust of the farmers in the technology and hence, decreasing the effective commercialization and diffusion (interviewee 2). Moreover, it was found that standardization has direct financial advantages at which smallholder farmers would benefit from at the end. These benefits mainly revolve around decreasing production costs, which in effect would reduce the total upfront cost of the overall asset. In addition to that, standardization would also reduce the overall transaction cost of technology installation, due to the usage of standardized components that would in turn result in having simplified contractual agreements, higher quality and safety levels for the farmers and a common commercial language of understanding (FAO, 2018).

Lastly, financial instruments, such as subsidies and taxes, can sometimes distort the market and hinder the uptake of solar irrigation technology. This mainly takes place when taxes are applied on imported components or when subsides are applied on fossil fuels and grid electricity. This would in turn represent a barrier to solar irrigation technology to be adopted, due to the competitive nature between solar pumps and fuel/electricity-based pumps (FAO, 2018). In addition to that, subsidies constitute a problem to the governments, as they are very costly to be implemented and could sometimes promote inefficient water use (interviewee 2). That's why the interviewee has recommended the use of "smart" subsidies that is intended to make sure that the poor smallholder famers can withstand the cost of solar irrigation technology, while avoiding the related risks as much as possible (interviewee 2). "Smart" subsidies can also promote green growth, and this can be done through introducing obligatory measures, that are combined with the solar irrigation systems, to ensure efficient water use and groundwater monitoring (FAO, 2018).

4.1.3. Financial Barriers from the Financial Institutions' Perspective

Financial institutions can represent a barrier for the adoption of solar irrigation systems, due to the risks associated with dealing with smallholder farmers. "Smallholder farmers usually find hardship in having access to formal financial institutions due to their low cash flows and the lack of collaterals" (interviewee 3). To understand the risks associated with financial

institutions, the Bank for International Settlement (BIS)[6] divides them into three main types: credit risks, market risks and operational risks. *Credit* risks are associated with loans given to borrowers, who are incapable to pay back, mainly due to shortage of income. *Market* risks are associated with price changes and the "unpredictability of equity markets, commodity prices, interest rates and credit spreads" (CFI, 2020, p.1). *Operational* risks are associated with the internal protocols of the financial institutions and are closely connected to legal and reputational risks (Talaat, 2018). Market risk and operational risk are out of the scope of this research; accordingly, credit is the main risk domain integrated within the research and will be accounted for in the next section, while discussing the microfinancing services provided to smallholder farmers to adopt solar irrigation technology.

In addition to credit risk at which most of the financial institutions get exposed to while dealing with smallholder farmers, high transaction costs also constitute as one of the barriers that slow down the adoption rate of solar irrigation technology. Transaction costs are not overlooked by both financial institutions and farmers who considered them very significant, as they represent the economic expenses needed for coordinating economic transactions within an institution. Hence, transaction cost is dominantly existent in rural financial market and more specifically in the activities that govern the coordination between borrowers (farmers) and lenders (financial institutions). According to De Guia-Abiad (1993), the level of the transaction costs is affected by two factors: 1) type of the bank, and 2) distance to the bank. Regarding the bank type, borrowers from the rural banks have higher transaction costs than borrowers from the non-rural banks; the reason behind this is mainly attributed to the high credit risk that is typically associated with smallholder farmers. Regarding the bank distance, long travel distance is also associated with high transaction costs and vice versa (De Guia-Abiad, 1993). Distance is a significant barrier to smallholder farmers and a main contributor to high transaction costs in credit (interviewee 3). This barrier is substantial for women in cultures where movement outside of the village is restricted. Financial institutions mostly prefer to be located in urban areas than in remote rural areas. Therefore, the digitization of banking services, and the usage of mobile banking is an essential facility that aims to integrate the remote communities and to lower the transaction costs of credits. An analysis of the usage of mobile banking services to pay for modern agricultural assets is to be discussed in the next section.

[6] BIS is an International financial institution which promotes international monetary cooperation. It Is owned by 63 central banks from various countries all over the world, representing 95% of the world GDP (BIS, n.d.).

4.2. Microfinancing Services for the Adoption of Solar Irrigation in Small Farms

This section analyses the microfinancing services available to farmers that could incentivize them to adopt modern agricultural technologies, such as solar irrigation. The section is divided into two parts: (i) the stakeholders and the financing actors involved in adoption of solar irrigation technology, (ii) the applicable payment facilities, credit facilities and non-financial facilities offered through financial institutions, with the focus on MFIs supporting the adoption of solar irrigation technologies in small agricultural farms. As explained in chapter 2, the target audience of these financing facilities are only the commercial and the semi-commercial farmers. Financing subsistence farmers is typically the role of humanitarian organizations, rural development banks, NGOs, and governments. The reason behind this is that most of financing services provided from MFIs are not applicable to subsistence farmers, as they could make their financial situation even worse, due to possible failures in loan repayments (interviewee 3).

4.2.1. Stakeholders Involved in the Adoption of Solar Irrigation Technology

Stakeholder theory is applied in this section to describe the composition of the value chain, where the financial institutions play an essential role to ensure the continuity and the sustainability of the operations. The value chain of the solar irrigation pumping market is divided into three main divisions: production/manufacturing, distribution, and consumption (KPMG, 2014). Each division has various stakeholders that have different roles in the value chain. Figure 6 shows the divisions and the stakeholders involved in solar irrigation, then a description about the role of each stakeholder follows.

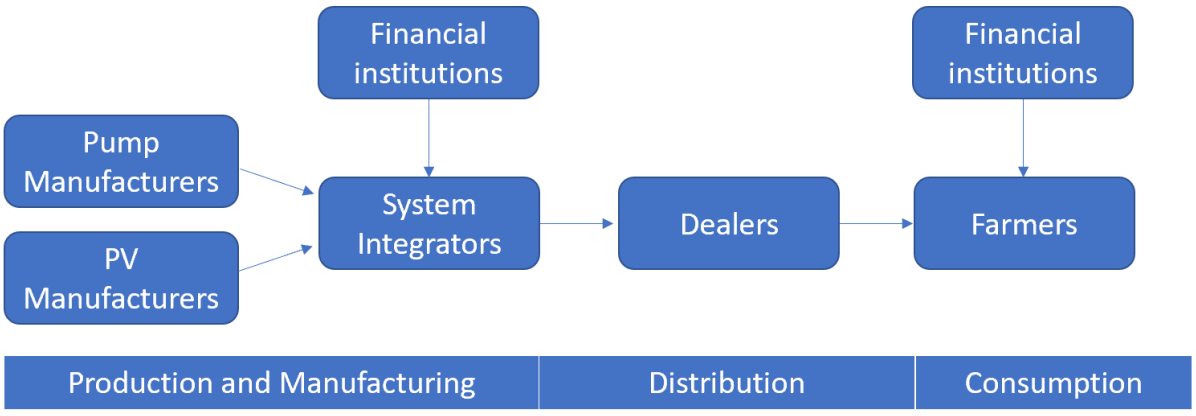

Figure 6: Solar irrigation stakeholders

In the p*roduction/manufacturing* division, there are three main stakeholders: pump manufacturers, PV manufacturers and system integrators. Pump manufacturers are responsible

to supply pumps to system integrators. PV manufacturers are the ones responsible for supplying PV panels to system integrators, System integrators are the ones responsible for providing integrated solutions for the customers. Some system integrators are also responsible for the provision of maintenance and after sales services. This is an essential aspect to smallholder farmers, as it increases their trust in the irrigation system. In the *distribution* division, the main stakeholders are the dealers. They are responsible for conducting deals with farmers, marketing for the technology and executing sales for completely integrated solar irrigation systems. Lastly, the *consumption* division includes the farmers who purchase the technology and adopt the solar irrigation system within their farms (CGIAR, 2017). They represent the demand force for the solar irrigation technology, which is impeded by the barriers described in section 4.1. Accordingly, to boost the demand side of solar irrigation, financial institutions would be relevant stakeholders. Different types of financial institutions can support the adoption of solar irrigation. However, this research focuses on MFIs and their relevant financial services that could be provided to smallholder farmers, as described in the following subsections.

As shown in Figure 6, financial institutions have a direct relationship with both system integrators and the buyers, i.e., smallholder farmers. This relationship is an opportunity for the financial institutions to diversify their loan portfolio, grow their financial products and improve the livelihood of the country that they are operating in. Two financing model categories are used to finance and to increase the adoption of solar irrigation in small farms: development models and business models (GIZ and FAO, 2018). Development models are mainly implemented through governments, NGOs, and non-profit institutions, aiming to improve the agricultural situation for farmers, through equipping them with modern agricultural technologies, such as solar irrigation, which would in turn contribute towards increasing the farm productivity and the overall development for farmers. The typical examples of financial development models are grants, subsides and infrastructure programmes (GIZ and FAO, 2018). The second category is business models, which are implemented by financial institutions, such as banks, MFIs and financial cooperatives. The aim of this model is not only to improve the overall economic growth of the targeted audience, but also to gain profits from the interest rate applied on the credit schemes provided to farmers (GIZ and FAO, 2018). Business financial models are typically more convenient for mature markets and are characterized by their sustainability, as both sides would share the benefits of their implementation.

4.2.2. Microfinancing Services Applicable to Solar Irrigation Technology

MFIs help the poor members of the society gain access to financial services. Some of the MFIs adopt the development financial model, described above, as they are considered to be one of the leading institutions that contribute towards reducing poverty and enhancing the livelihood of the poor people, which often include smallholder farmers (GIZ and FAO, 2018). Before looking into the financial services that can be provided by MFIs, it is essential to look at whether Solar Powered Irrigation System (SPIS) would fit the microfinance loan range or not. Small solar water pumps that require at most 500W typically cost between USD 600 to USD 800 (Dalberg, 2019). Interviewee 3 considered that this product can be easily financed by MFIs. In the past, most of the loans provided from MFIs are between 100 and 300 USD; however, the loan range has significantly increased, giving a better chance for farmers to utilize MFI services and to purchase capital intensive assets, such as solar irrigation pumping systems (GIZ and FAO, 2018). The main microfinancing products/services that MFIs provide to small holder farmers to assist them to adopt solar irrigation technology are: 1) microloans, 2) value chain financing, 3) mobile banking, and 4) non-financial services. Each financial service is to be demonstrated in detail in this section. It is also worth mentioning that these services are meant to be provided mainly to commercial and semi-commercial smallholder farmers.

4.2.2.1. Microloans Between MFIs and Smallholder Farmers

Microloans provided from MFIs to farmers are characterized by quick loan disbursement and frequent repayment rates. Therefore, the most predominant type of microloans provided to farmers who lack cash flow for their day-to-day operations is “working capital loans” that range from 4 to 12 months and are repaid on monthly or weekly or daily basis. (GIZ and FAO, 2018). Working capital loans has its highest effective impact in agri-finance in the field of cash flow management. However, from the solar irrigation perspective, working capital loans are not effective to overcome the barriers, stated in section 4.1, which the farmers mostly suffer from while adopting solar irrigation systems in their farms. Hence, the provision of customized microfinance loans, catered specifically to smallholder farmers, is currently on the agenda of many MFIs. This implies the significance of having strong ties and personal relationships between lenders (MFIs) and borrowers (smallholder farmers). In order to have a sustained relationship that are beneficial to both stakeholders, specialized loan officers should have the relevant background information about the agricultural sector in general and about Agri-finance in particular (Physik, 2018). This would assist them to overcome the information asymmetry and to better understand the agricultural portfolio,

through being exposed to specialized loan officers training, that mainly consists of classroom instruction and field-based training (GIZ and FAO, 2018). Specialized training courses could prepare loan officers to better manage agricultural loans and to customize them based on the farmers' needs. Loan customization would in turn attract more farmers to increase their adoption of solar irrigation systems, given the existing financial capacity provided from MFIs and given the increasing loan ranges that are currently provided by MFIs to better equip farmers with capital intensive assets. Farmers' accessibility to MFIs is certainly much easier than their accessibility to formal classic financial institutions, due to the presence of more flexible payment terms and collateral conditions as well as the existence of better understanding of the poor's needs. Despite the flexibility that exists within MFIs, there are still some requirements needed from smallholder farmers to ensure having loan repayments within the contracted timeframe. These requirements are about the identification documents, the presence of at least one year experience in the agricultural sector, good credit record in repaying the past loans, the existence of soft collaterals or guarantors and a clear purpose for the loan usage (GIZ and FAO, 2018). MFIs also have a comparative advantage over classic financial institutions, as they can offer loans to both single farmers and to groups of farmers as well. This is typically named as "Planting Model Group", which is created to assist farmers to specifically purchase solar irrigation pumping systems. This model is established for farmers who trust each other, as all group members should be able to provide a guarantee for one another and if a farmer fails to repay his/her loan, the other members must take the responsibility of the repayment (GIZ and FAO, 2018). Microfinance loans are unilateral financial agreements between farmers and MFIs. More information about multilateral agreements is provided in the value chain financing scheme demonstrated below.

4.2.2.2. Value Chain Financing Between MFIs, Chain Actors, and Smallholder Farmers

Value chain financing, also known as asset financing or vendor financing, is a type of financing that allows for investments and loans to be made along the value chain, hence it requires multilateral agreements between various stakeholders. It is a partnership between three main stakeholders: MFIs, upstream or downstream actors and farmers. Upstream and downstream actors serve as financial intermediaries, allowing farmers to get financial services (mainly loans) that they would not otherwise be able to receive from traditional financial institutions (Izzi et al., 2021). In the case of solar irrigation systems, upstream actors can be system integrators/dealers, who are the ones typically responsible for supplying and distributing solar irrigation pumping systems to farmers. System integrators will access finance

from MFIs and then they will deal directly with the farmers to supply them with the solar irrigation systems, with customized loan terms. The same tri-sector partnership can happen between MFIs, downstream actors, and farmers. Downstream actors are the food traders who provide in advance funding to farmers for the food which they will buy later, this will consequently provide farmers with enough cash flow to purchase solar irrigation systems with the money taken from food traders. This option is preferred by many food traders, as they are certain that both the quality and the quantity of food produced from solar irrigation systems will be adequate for future profit from the food market. In addition to that, value chain financing would give a comparative advantage to food traders, as it would guarantee them earning the loyalty of the farmers, which would in turn prevent farmers from selling their crops to any competing buyers (GIZ and FAO, 2018).

Value chain financing gives the opportunity for the upstream/downstream actors to study the financial situation on the ground and to decide whether it is the correct decision to provide farmers with value chain loans or not (interviewee 5). This type of finance also boosts the value chain's productivity and competitiveness, as well as it creates a win-win situation for all the stakeholders involved (GIZ and FAO, 2018). From the farmers' perspective, they can make use of this type of finance through obtaining customized loans, which could fit their harvesting schedule and could allow for more flexibility in the payments, as they can start repaying the loans some months, depending on the crop type, after the disbursement and in several installments. From the suppliers' and traders' perspective, a guaranteed profit is granted due to the interest earned and the value chain improvements. From the MFIs' perspective, value chain finance has a prominent positive impact on reducing the typical risks related to agricultural finance, as MFIs through this financing type, are no longer dealing with farmers, but with high profile upstream and downstream actors, which significantly reduce the credit risk, faced by financial institutions. In addition to that, low transaction costs are incurred in the credit process, as money transfer and financial transactions are more facilitated if they are between MFIs and value chain actors. Despite all the advantages that value chain finance is characterized with, the charged interest rate is typically higher than the traditional microfinance loan that takes place between MFIs and farmers. The reason behind that is due to compounding the MFI's interest with the financial mediator's interest, leading to a high interest rate that can reach up to 30% (GIZ and FAO, 2018).

4.2.2.3. Mobile Banking Services Provided by MFIs to Smallholder Farmers

Digitization of the financial services has grabbed the attention of many financial institutions due to its strong facilitation for financial processes, including but not limited to payment, money transfer and credit transactions conducted by smallholder farmers. As mentioned in section 4.1, physical distance resembles a barrier for both smallholder farmers to have the adequate financial accessibility and for financial institutions to diversify their portfolios and to reach remote communities, especially within the rural areas. Consequently, mobile banking is an emerging trend adopted by several MFIs to tackle the aforementioned barriers. When it comes to leveraging mobile banking systems, MFIs often pursue one of two strategies, each having different implications for the level of investment required and the functionality supplied to customers. The first strategy uses the bill pay functionality through utilizing the existing mobile banking provider capacities, like the one typically used for paying gas/water bills. This strategy facilities loan disbursement, saving mobilization and bulk payments, which would in turn make it easier for smallholder farmers to repay the loans to MFIs or to the upstream/downstream actors, as explained in the section on "value chain financing". This strategy is both quick and cheap to be implemented by MFIs, as what is only needed is to import the data and reconcile them manually (Hanouch & Rotman, 2013). The second strategy is more sophisticated, yet it is more effective in mobilizing savings. This strategy invests in a better off technology that makes MFIs capable to link the mobile wallets of the customers to their MFI accounts, allowing them to have accessibility to their accounts via mobile phones, facilitating the cash-in and cash-out transactions. The implementation of the second strategy requires higher investment cost compared to the first one; so, the early movers to this technology are the ones who suffer the most from the high investment cost, which would likely decrease as the technology is adopted by more institutions and as the processes become more standardized (Hanouch & Rotman, 2013).

The adoption of mobile banking services in rural areas that are catered specifically to smallholder farmers to repay loans related to investments in solar irrigation technology is advocated in one of the experts interviewed for this research (interviewee 3). Expanding the coverage of financial accessibility is one of the cornerstones that characterizes mobile banking, which in turn has led to the creation of new innovative business models that serve towards solar irrigation financing, such as Pay As You Go (PAYGO) model. However, in order to utilize mobile banking services in the most effective manner, there are some key factors that should be taken into consideration by MFIs, for them to ensure the effectiveness of such measure.

Educational standards, rate of mobile phones usage, electrification rate and distance to mobile banking agents are all key determinants for successful utilization of mobile banking services (Kirui; Okello and Nyikal, 2010). Based on a study conducted in Kenya, it was found that the distance to mobile banking agent has an inverse relationship with the usage of mobile banking services. The conclusion of the study is the urgent need of expanding the coverage of mobile banking agents in rural areas, in order to avoid market failure caused due to financial inaccessibility. Lack of adequate float[7] also represents a constraint in mobile banking services, especially due to the receival of a lot of cash remittances between farmers/people living in remote areas (Kirui; Okello and Nyikal, 2010). Accordingly, "the availability of sufficient "float" of funds to expedite transfers into and from farming communities" is essential to overcome this barrier (Kirui; Okello and Nyikal, 2010, p.15). Based on these findings, mobile banking is proven to be a good remedy to a lot of the financial barriers that restrict smallholder farmers from adopting solar irrigation systems. However, it still needs to be complemented by more concrete plans from the policymakers and private sector to ensure the presence of sufficient infrastructure and high rural literacy levels (Kirui; Okello and Nyikal, 2010).

4.2.2.4. Non-financial Services

The provision of financial services to smallholder farmers is not sufficient for them to be able to adopt modern agricultural technologies, such as solar irrigation systems. In other words, the poverty that exists within the agricultural sector does not only lie in the money deprivation, but also in the deprivation of the capabilities that enhance the overall living standards of one's life. Hence, the provision of education, infrastructure, health care etc. are all essential factors that contribute towards breaking the poverty vicious cycle (Goubert, 2021). This concept is also applied on MFIs as they are characterized by their mandate of helping poor members of the society gain access to financial services. Gaining access to financial services is significant for the provision of liquidity through loans and other financial products as described above; however, it should be complemented by other non-financial services that are essential to be added in the microfinance package.

Non-financial services (NFS) can support the smallholder farmers in various dimensions, which would enrich their knowledge on which financial service to choose that would best suit them to adopt solar irrigation technology. The various dimensions of NFS mainly revolves around education and business-related services (Goubert, 2021). These

[7] "Float is money within the banking system that is briefly counted twice due to time gaps in registering a deposit or withdrawal" (Segal, 2020, p.1).

services are not only provided by MFIs, yet there are still some intermediary organizations such as farming cooperatives and civil society institutions which promote the solar irrigation technology and educate them to the farmers. Some of these organizations are also capable to provide finance or guide farmers on the possible financial mechanisms that could support them to purchase solar irrigation systems. Accordingly, application of the stakeholder theory is revised again and below is an updated version of the relevant solar irrigation stakeholders along the value chain. The main difference between figures 6 and 7 is the introduction of the intermediary organizations that most of the time have a direct contact with farmers.

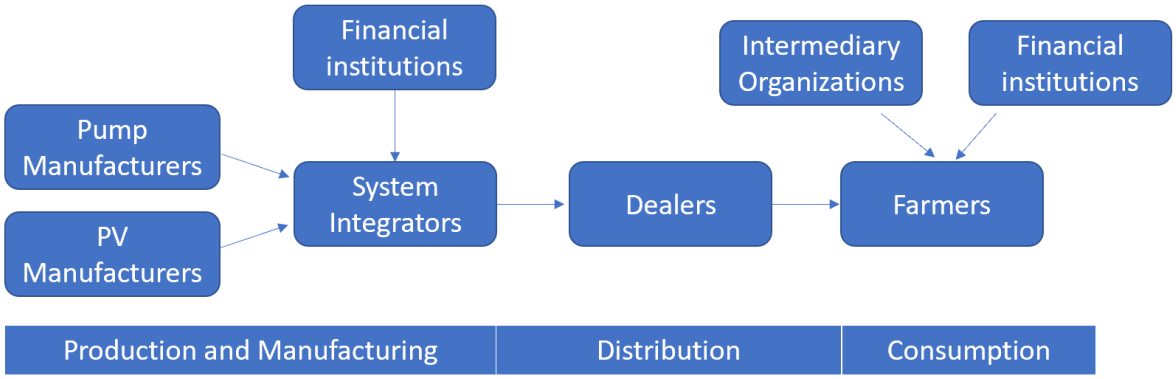

Figure 7: Solar irrigation stakeholders (revised version)

Financial education should be a prerequisite, especially for smallholder farmers, who want to have better financial accessibility. Governments, international organizations, and MFIs strive to provide programmes that aim to improve the financial literacy among smallholder farmers. The objective of these programmes is to educate the farmers to be "more aware of financial risks and opportunities, to make informed choices, to know where to go for help and to take other effective actions to improve their financial well-being" (Aggarwal et al., 2014, p.37). MFIs provide these programmes, as part of their NFS. These programmes assist smallholder farmers to take sound financial decisions and to prevent them from being vulnerable to financial misjudgments. Financial education, provided by MFIs, support the clients to better understand how to sustainably manage their financial resources, allowing them to spread their income out over time and to save money. Business-related services, provided as part of NFS, are also essential to better equip smallholder farmers with the commercial mindset. This could be achieved through providing farmers with legal advice, technical or business development trainings, etc. Accordingly, based on the above-mentioned services that MFIs could provide in addition to its regular financial services, it can be concluded that NFS is an

efficient tool to support farmers increase their productivity and to assist them in increasing their resilience towards shocks, whether climatic or economic (Goubert, 2021).

NFS can be integrated within MFIs through three different models, at which each one of them leads to different performance and management outcomes. The three models are as follow: 1) linked, 2) parallel and 3) unified NFS models. The linked model involves two independent entities providing services; MFI does not provide non-financial services directly, but instead forms a relationship with another institution to do so. This model is applicable to schemes that require specialized non-financial skills, which might not be found as an area of expertise inside the MFI. These specialized skills can be related to technical assistance in agriculture and irrigation technologies, at which solar irrigation can fit in this model. Despite the fact that MFIs most of the time have limited control on the quality outcome of the trainings provided by the external partners, MFIs remain to have the full control on knowing the exact cost of the NFS, which would in turn give MFIs the privilege of handling the NFS sector in a cost-effective manner (Lanao & Serres, 2009).

The second model of NFS is the parallel model, at which financial and non-financial services are provided by the same MFI, but under different programmes and departments. The advantage of this model is the direct control on each department, allowing the presence of specialized staff that are professional in a specific area of expertise, whether it is financial or non-financial services. However, this model can represent a burden to some MFIs, due to possible financial and administrative challenges that could lead to the inability to implement a comprehensive scheme, negatively affecting the learning outcomes of the beneficiaries. The third and the last model of NFS is the unified model, at which financial and non-financial services are offered together to beneficiaries and are provided by the same staff. This model ensures a comprehensive scheme that could provide farmers with both the knowledge and the financial services needed to run their farms. The financial staff working in this model should receive intensive training to be able to provide the clients with the relevant knowledge, based on the sector that they are working in (Lanao & Serres, 2009).

In this regard, unified model appears to be the most cost-effective, as the presence of a fully-fledged NFS model within the already existing financial services is certainly lower in cost, in comparison to constructing a new department mandated to provide NFS or to outsource NFS from another independent entity, as described in the parallel and linked models, respectively. In conclusion, NFS is an essential element to be provided by MFIs despite the

generated operational costs for its conduction (Lanao & Serres, 2009). These operational costs are compensated anyway by a higher portfolio yield, which would in turn result in a possibly higher rate of return, due to the integration in various markets that could not possibly be engaged unless NFS are provided.

4.3. Evaluation of Microfinance from the Perspective of Smallholder Farmers

This section answers the third sub-question, as it evaluates the effectiveness of microfinance in tackling the barriers that are faced by smallholder farmers to adopt solar irrigation technology. Accordingly, the knowledge gained from section 4.1 and 4.2 is used to assess how effective microfinance is in this perspective. The underpinning theory that is applied to evaluate the effectiveness is the Theory of Change (ToC). In this section, the advantages and drawbacks of microfinance in agricultural context are to be demonstrated, in order to provide an objective overview on the extent of what microfinance can offer to the smallholder farmers and can contribute towards having more sustainable irrigation systems within the small farms. It is essential to realize that the causality relation that is present within the theory of change model is based on the data/results presented in the previous two sections, the researcher's own analysis and empirical evidence from the literature.

4.3.1. Compatibility of Microfinancing Services Using Theory of Change

This subsection looks into how the four microfinancing services described in section 4.2.2., i.e., microloans, value chain financing, mobile banking, and NFS, can contribute towards some of the SDGs. To see this type of connection between an intervention and a long-term impact, the ToC is applied. The underlying assumption at which the ToC is based on, revolves around the context that the intervention will operate in (RVO, 2018). In other words, the presence of a fully operational MFI that has a previous record within the agricultural sector, as well as, the existence of specialized staff and digitization platforms, are all considered as fundamental assumptions, without which the interventions (inputs) cannot operate properly. Figure 8 demonstrates the cause-effect relationships between the three different elements of ToC. Following the figure, an explanation about the problem and the causal relations between the interventions/inputs and the potential outputs, outcomes and impacts is to be demonstrated.

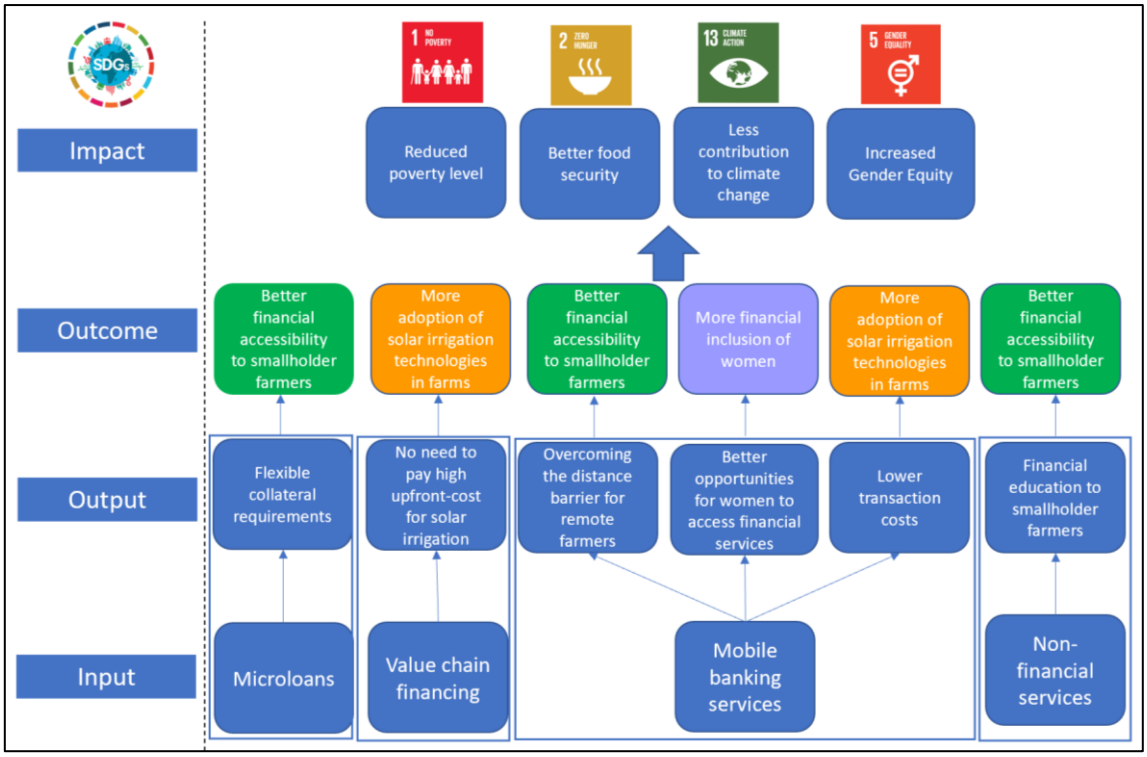

Figure 8: Theory of change (own work)

4.3.1.1. Problem Definition

The problem the ToC is based on is the lack of the affordability of smallholder famers to adopt modern agricultural technologies, with a focus on solar irrigation. The lack of affordability is dependent on various financial barriers which were addressed in section 4.1 and were divided into three main perspectives: 1) financial barriers from the smallholder farmers' perspective, 2) financial barriers from the solar irrigation perspective, and 3) financial barriers from financial institutions' perspective. Table 5 below summarizes the main barriers tackled in section 4.1. to act as a starting base for building the above diagram shown in figure 8. The summarized barriers are compared with the "ToC Output" in sub-section 4.3.1.2. to evaluate to what extent are the "ToC inputs" capable on overcoming the barriers or can contribute towards alleviating them.

Table 5: Multi-perspective financial barriers

Financial barriers from the smallholder farmers' perspective	1) Financial literacy 2) Farmer's low income 3) Credit discrimination between men and women 4) Farmer's risk perception
Financial barriers from the solar irrigation perspective	1) High up-front cost 2) Lack of standardization in solar irrigation technology 3) Taxes on imported components / subsidies on diesel-powered irrigation
Financial barriers from financial institutions' perspective.	1) Credit risk 2) High transaction costs 3) Low proximity

4.3.1.2. *Causal Relation Between Input and Output*

Based on the above-mentioned barriers for the adoption of solar irrigation systems by smallholder farmers, MFIs play a significant role in overcoming these barriers through providing microfinancing services that accommodate the low affordability and literacy rates among the smallholder farmers and at the same time can equip farmers with better agricultural assets, which would in turn increase the overall agricultural farm productivity. Figure 9 presents a closer look into the input and the output of the ToC. The four inputs represent the four main microfinancing services offered by MFIs. Each one of these services, if implemented properly, would lead to an output which would in turn result in realizing most of the financial barriers demonstrated in Table 5. The four inputs and their possible resultant outputs are described below.

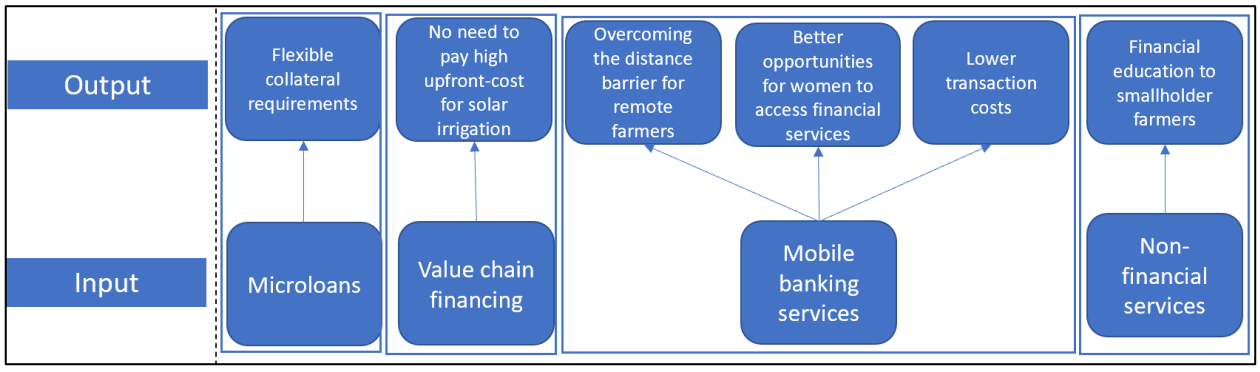

Figure 9: Causal relation between input and output

(a) *Microloans* are characterized by their flexibility and the existence of close relation between borrowers and lenders; this would consequently lead to *the provision of flexible collateral requirements that fit the low incomes of the* smallholder farmers. Microloans serve as essential financial instruments especially to low-income groups who do not have financial accessibility to loans from classic financial institutions.

(b) *Value chain financing*, due to its dependence on financial intermediaries (upstream/downstream actors), would allow the farmers to easily purchase solar irrigation systems, either from system integrators or from food traders, on flexible payment terms and *without the need to pay high up-front cost* at the purchase time.

(c) *Mobile banking* and digitization of banking services also has a direct output on farmers, as it can help farmers to provide them with easier payment and money transfer facilities *without the need of getting out of the farm*. It also gives the *opportunity for women to conduct their financial transactions remotely*, as the distance represents a barrier to them, especially those involved on daily household tasks. Lastly, the provision of mobile banking services contributes towards the *reduction of the transaction costs*, as these costs are directly proportional to the bank distance, which is now eliminated after the usage of mobile phones to pay for the installments or to transfer money (De Guia-Abiad, 1993).

(d) *Non-financial services* contribute towards *educating farmers* about the financial instruments and terminologies, which would in turn increase their overall awareness on how to better deal with MFIs.

ToC outputs shown in Figure 9 and explained above reflect that most of financial barriers for the adoption of solar irrigation systems can be alleviated through the implementation of the aforementioned four inputs. However, three barriers, i.e., farmers' risk aversion, lack of standardization in solar irrigation technology, and taxes on imported components/subsidies on diesel-powered irrigation, cannot be overcome by microfinancing services.

4.3.1.3. Causal Relation Between Output and Outcome

All the outputs demonstrated in the previous section could contribute towards achieving better-off outcomes to smallholder farmers and to MFIs. Figure 10 presents a closer look into the outputs and the outcomes of the ToC. The three main outcomes retrieved based on the ToC are: 1) better financial accessibility to smallholder farmers, 2) more adoption of solar irrigation

technologies in small farms, and 3) more financial inclusion of women. The relationship between the outputs and outcomes are based on empirical evidence retrieved from literature.

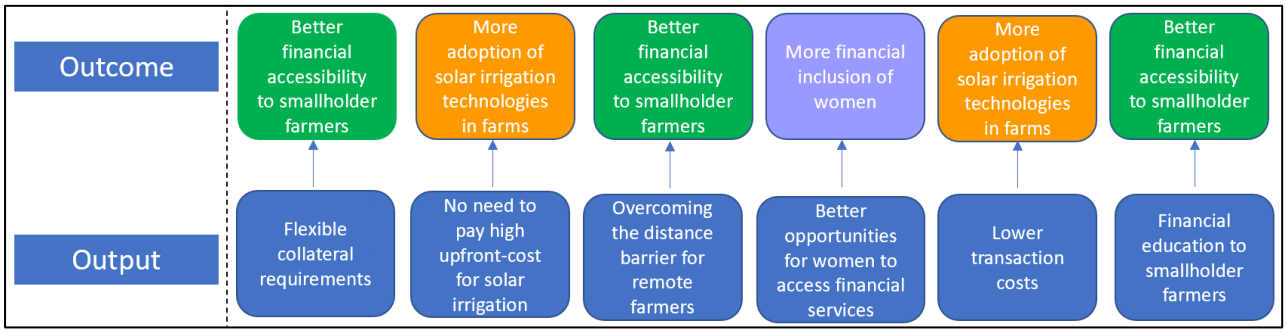

Figure 10: Causal relation between output and outcome

By tracing the outcomes, it can be concluded that having *better financial accessibility* is mainly achieved due to the *elimination of the distance barrier* between MFIs and farmers (Linh et al, 2019), the *implementation of financial educational programmes* to smallholder farmers (Widhiyanto, 2018), and the existence of *flexible collateral conditions* (Karanja et al, 2015). The *adoption of more solar irrigation systems* is also a causal effect from the *unnecessary payment of high upfront cost* of solar irrigation at purchase time (Kumar et al, 2019), as well as *the reduction of the associated transaction costs* (Takeshima, 2010). Lastly, *financial inclusion of women* is achieved due to having better opportunities for *women to access financial services remotely*, thanks to the presence of mobile banking services (Ragui, 2017)

4.3.1.4. Causal Relation Between Outcome and Impact

The last step of ToC is to link the three outcomes with the expected impacts. The impacts shown in Figure 11 are retrieved from the SDGs and they represent the long-term intended end results of the intervention. The expected impacts retrieved from the ToC are: 1) reduced poverty level, contributing towards SDG 1 (No Poverty), 2) Better food security, contributing towards SDG2 (Zero hunger), 3) less contribution to climate change, contributing towards SDG 13 (Climate Action), and 4) increased gender equality, contributing towards SDG 5 (Gender Equality). As Figure 11 shows, there is a causal effect relation between the three outcomes of the ToC and the four impacts that are based on the SDGs. This causality relationship can then draw a conclusion that the ToC interventions, i.e., the four microfinancing services potentially have an indirect causation to the accomplishment of the four SDGs. Given the indirect relation between microfinance and some of the SDGs, it is still worth mentioning that this relation is not always the case, and it only exists in a perfect scenario where synergies between MFIs, farmers and policymakers are present and in strong ties.

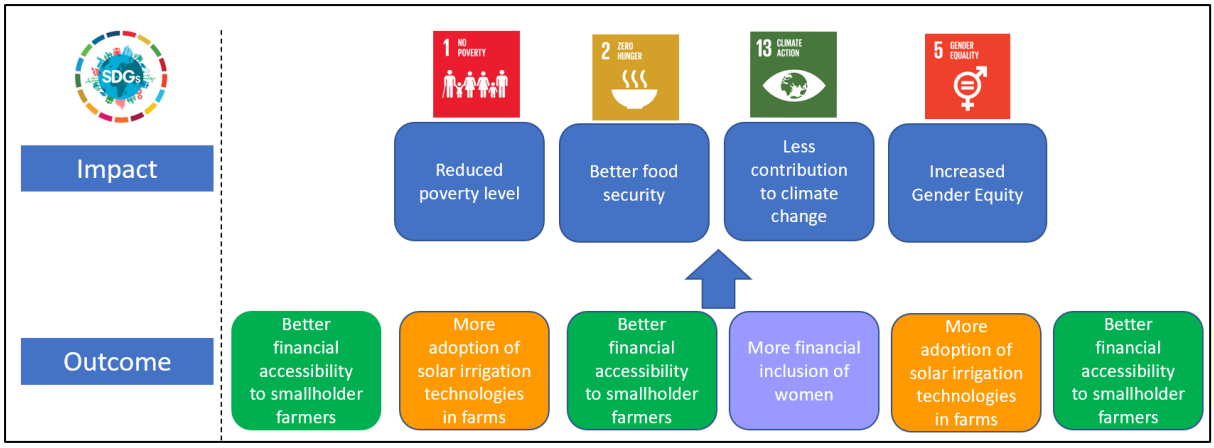

Figure 11: Causal relation between outcome and impact

4.3.2. Drawbacks of Microfinance in Agricultural Context

Despite the optimistic overview of how microfinance in the agricultural sector can contribute towards the achievements of multiple SDGs, the MFIs also have several drawbacks. These drawbacks are addressed to improve practical applications and to ensure the presence of a greater influence of microfinance on rural development across the world.

The first drawback is the uncertainty of the effectiveness of rural microfinance in enhancing the livelihoods of the smallholder farmers. This uncertainty also applies to the effectiveness of microfinance in the adoption of modern agricultural technologies, solar irrigation systems being one of them. The uncertainty originates from the challenging nature of the methodologies used to assess the impact causality despite the progressive existence of quasi-scientific approaches that depend on the usage of randomized control trials (Marr, 2012). Additionally, the implementation of microfinance interventions has shown high dependence on social cohesion, which can be defined as "the capacity of a society to ensure the well-being of all its members, minimizing disparities and avoiding marginalization" (Council of Europe, 2018, p.14). This capacity varies from one society to the other, resulting in different impact casualties in different locations. This would in turn make it difficult to draw generic conclusions on the effectiveness of microfinance in the agricultural sector (Marr, 2012).

The second drawback is the limited compatibility of traditional microfinancing services with the expected financial services in rural environments. This limited compatibility stems from the small size and the short maturity of the traditional microloans offered by MFIs, which would in turn make it inconvenient to smallholder farmers to either cultivate their crops or invest in modern agricultural assets within their farms. Not all MFIs can accommodate flexible

payments to farmers and if they do so, they suffer from stability problems due to the high credit risk in rural environments (Marr, 2012)

The third drawback is the inability of MFIs to fully operate in rural environments, due to the lack of adequate infrastructure. Poor physical infrastructure such as roads, electricity systems, mobile networks, etc. as well as the lack of marketing and distribution channels, are the most significant hurdles that hinder the effectiveness of microfinancing services to smallholder farmers. To improve the efficacy of microfinance in rural areas, essential stakeholders such as national and local governments need to partner with MFIs, as they can help to create the required conditions for microfinance to operate in agricultural communities. Similarly, in order to meet the financial demands of farmers, Marr (2012) recommends that microfinance is supplemented with other financial mechanisms, such as subsidies and grants that could be catered specifically for the adoption of solar irrigation technologies.

All the three drawbacks are essential to be overcome in order to improve the implementation of microfinancing services in rural areas, which could result in more adoption of solar irrigation systems. Recommendations are presented in the next chapter along with the further research areas that need to be developed.

5. Conclusions

In this chapter, the answer to the main research question is given based on the findings presented in chapter 4. Then, recommendations for better implementation of microfinance to smallholder farmers are addressed, a reflection on the research process is provided, and finally directions for future research are drawn.

5.1. Answer to the Main research Question

To understand the extent of how MFIs can support smallholder farmers in the adoption of modern agricultural technologies, such as solar irrigation, the research has followed the following steps. First, the financial barriers that impede the diffusion of solar irrigation systems in small agricultural farms have been identified and examined from three perspectives: farmers' perspective, solar irrigation perspective and financial institutions' perspective. Then, stakeholder theory was applied to identify the relevant actors in the solar irrigation value chain. Grounding the research in stakeholder theory is essential due to the presence of various stakeholders who play a role in the adoption of solar irrigation systems. Accordingly, the role of each stakeholder was identified early on to understand the dynamics of the value chain and the functions of the relevant stakeholders in financing solar irrigation technology. The applicable financial services were based on the choice of the farmer segmentation, as well as the product price. Accordingly, it was concluded that the examined microfinancing services can fit the price range of solar irrigation systems but are only applicable to semi-commercial and commercial farmers. After the identification of the target group and the financial services applicable to it, an evaluation of the success of microfinancing services was demonstrated by applying the ToC. Following that, the relevant drawbacks of the microfinance applications were addressed to provide an objective overview about this financing type and the extent of support that it can leverage to incentivize smallholder farmers to adopt solar irrigation systems. The research has also concluded the essence of involving intermediary organizations such as farming cooperatives and civil society institutions as the relevant stakeholders of solar irrigation, due to their capacity of educating farmers about the technology and guiding them on the possible financial mechanisms applicable to this irrigation technology. Hence, the research has contributed to the revision of the stakeholder theory application, that was previously included in the literature, through the inclusion of the intermediary organizations in the solar irrigation value chain.

The above summary represents the steps followed to answer the key research question, as stated below:

To what extent can microfinance enable smallholder farmers to adopt modern technologies for improving agricultural output?

In conclusion, the investigation of rural microfinance reveals that MFIs have potentially positive impact on rural economic life and they are considered as the key vehicles for the process of financial deepening in the rural areas. Financial deepening mainly depends on the savings level of the financial assets and is typically followed by increasing the borrower's investment capacity (this could also be translated to more investments in solar irrigation systems). However, it can still be concluded that this activity is a not risk-free one, due to the presence of failure probability that can be induced either by national crisis or by the MFI's lack of management. This could in turn result in losing both the financial capital and ruining the social capital relationship that should exist between the clients and the MFIs (Moll, 2005).

5.2. Recommendations

This subsection provides recommendations to maximize the privileges of MFIs in the agricultural context and to best incentivize smallholder farmers to use the services provided from MFIs to adopt solar irrigation systems. The recommendations listed below are mainly directed to MFIs and to governments.

1) Focusing more on financial stability

MFIs need to focus more on achieving financial stability. This financial objective is accomplished through enhancing the institutions' capacity to withstand financial shocks that either originate from the adverse conditions of the clients or from the national economic crisis that could exist in the country that the MFI operates in. Achieving financial stability can be undertaken by MFIs through 1) diversifying the loan portfolio to reduce the negative consequences of covariant risks faced by rural residents, and 2) accumulating reserves through generating profits; this should not be the main objective of the MFI, yet it is an essential requirement for continuation (Moll, 2005)

2) Expansion towards new clients

In order to best serve all the segments of the smallholder farmers to adopt modern agricultural technologies, MFIs should not restrict themselves to a narrowly defined group, as this could possibly lead to vulnerability in terms of financial stability. Focusing on only one

type of clients results in having the MFIs to overlook the positive effects that could be gained in widening the financial accessibility to rural populations. Hence, it is essential for MFIs to expand their facilities in different sectors and to provide new financial services that accommodate for the sector that they operate in (Moll, 2005).

3) More governmental support to MFIs

Governmental support is an essential element for the growth of the microfinance sector. This is mainly due to the governmental capacity to assist MFIs to gain legal status and to put a regulatory framework for their operation in line with the national legal system. It is recommended to seek governmental support at the initiation of the MFI, as this would facilitate saving mobilization, credit provision, microinsurance and money transfers. These facilitations would in turn allow MFIs to leverage economies of scale, allowing them to expand geographically and to cover more rural areas (Moll, 2005). Lastly, not only does the visible hand of the government work towards addressing market failures that could result from the mismatch between credit supply and demand, but it also works towards providing better-off infrastructure platforms at which MFIs can benefit from to avoid paying high amounts of fixed costs that could result in first mover and coordination problems (Beck, 2015).

5.3. Reflection on the Research Process

It was necessary to segment the main research question into three sub-questions, results of which give a conclusive answer to the main question. Large portion of the results depended on interviewing experts. The interviewing process was insightful, as it gave valuable qualitative data on two different fields at which this research tries to connect: solar irrigation and microfinance. Combining both fields together was challenging as it has not been extensively researched and so the academic literature is rather sparse, that is why interviews were essential to connect the points together. Large portion of my answer to the third research sub-question is the application of the ToC model, which was mostly dependent on my own analysis of the first two research sub-questions, supported by empirical evidence.

5.4. Future Research Directions

This subsection identifies the future research directions that could overcome the limitations of the current research. Due to time constraints and the period of the research, this thesis focused only on microfinance and its relation to the adoption of solar irrigation systems, as a ‘test case’ for modern agricultural technologies. Even though microfinance is significantly essential when it comes to financing projects to low-income groups, such as smallholder

farmers, it would be better for future research to examine other financing services, that could be provided from institutions other than MFIs. This would include studying the financial mechanisms provided from governments, rural banks, classic financial institutions, and financial co-operations. Furthermore, the focus on microfinance only has resulted in overlooking the financial mechanisms applicable to subsistence farmers, due to the inadequate application of microfinance for these farmers. Subsistence farmers are one of the three segmentations of the smallholder farmers who receive financial assistance from organizations other than MFIs, such as humanitarian organizations, rural development banks, NGOs, and governments. Accordingly, studying rural finance in general, without focusing only on microfinance, would result in a holistic overview of the opportunities that smallholder farmers, including subsistence farmers, can utilize to adopt modern agricultural technologies, such as solar irrigation systems.

This research also focused only on the *credit risk* as the main risk domain that was accounted for in the discussion of the microfinancing services catered to smallholder farmers to adopt solar irrigation technology. Credit risk is the most predominant risk type that exists between borrowers and lenders; however, it would be better for future research to account for the two other types of risks, named as *market* and *operational* risks to have a more comprehensive view on the risk factors that surround MFIs.

Lastly, the qualitative data included in this research depended on the literature and semi-structured interviews. Although interviewing allows for more freedom and elaboration of responses, Payne and Payne (2004) suggest that there may be prejudice from the interviewees' perspective. Accordingly, it would be better for future research to extend the qualitative interviews in terms of numbers and stakeholders. Additionally, the inclusion of quantitative data through surveying farmers and MFIs could have been useful to conduct credible impact assessment for the ToC model application.

References

Adhikari, S., Mahapatra, P., Sapkota, V., & Puppala, S. (2019). Characterizing emissions from agricultural diesel pumps in the Terai region of Nepal. *Atmosphere*, *10*(2), 56. https://doi.org/10.3390/atmos10020056

Agrawal, S., & Jain, A. (2016). Sustainability of Solar Based Irrigation in India- Key determinants, challenges and solutions. *Council on Energy Environment and Water*, *December*. https://www.ceew.in/sites/default/files/CEEW-Sustainability-of-Solar-Based-Irrigation-in-India-12Dec16.pdf

Agrawal, S., & Jain, A. (2018). Financing Solar for Irrigation in India. Council on Energy, Environment and Water (CEEW). http://ceew.in/pdf/CEEW - Financing Solar for Irrigation (SPIS)17Jan18.pdf

Agrawal, S., & Jain, A. (2019). Sustainable deployment of solar irrigation pumps: Key determinants and strategies. *Wiley Interdisciplinary Reviews: Energy and Environment*, *8*(2), 1–14. https://doi.org/10.1002/wene.325

Aggarwal, N., Gupta, M., & Singh, S. (2014). Financial Literacy among Farmers: Empirical Evidence from Punjab. Pacific Business Review International, 6(7), 36–42.

Ajah, E. A., Igiri, J. A., & Ekpenyong, H. B. (2018). Determinants of access to credit among rice farmers in Biase Local Government Area of Cross River State, Nigeria. *Global Journal of Agricultural Sciences*, *16*(1), 41. https://doi.org/10.4314/gjass.v16i1.6

Alves, Dinara & Pinto, Marinaldo & Damasceno, Ana & Grah, Vanessa & Botrel, Tarlei. (2014). Cost Analysis of Pumping Water Using Solar Energy and Diesel in Drip Irrigation. IRRIGA. 1. 1601-1608. 10.12702/ii.inovagri.2014-a215.

Bayram, Fatih & Yıldırım, Murat & Oğuz, Ahmet & Gunay, Gulay. (2017). Financial Literacy Level of Individuals and Its Relationships to Demographic Variables. Mediterranean Journal of Social Sciences. 8. 10.5901/mjss.2017.v8n3p19.

Beck, Thorsten. 2015. Microfinance: A Critical Literature Survey. IEG working paper,2015/No.4; Washington, DC: Independent Evaluation Group. © Independent Evaluation Group, World Bank Group.

BIS - overview. The Bank for International Settlements. (n.d.). https://www.bis.org/about/index.htm?m=1%7C1.

Capacio, J. L. D., Dios, E. S. De, & Tulder, R. Van. (2018). Breaking barriers in agriculture financing : of agriculture value chains. July, 1–125.

Chazarra-Zapata, J., Molina-Martínez, J. M., Cruz, F.-J. P., Parras-Burgos, D., & Ruíz Canales, A. (2020). How to reduce the carbon footprint of an Irrigation community in the south-east of Spain by use of solar energy. *Energies*, *13*(11), 2848. https://doi.org/10.3390/en13112848

Christen, Robert Peck and Anderson, Jamie (2013): Segmentation of Smallholder Households: Meeting the Range of Financial Services in Agricultural Families. CGAP Focus Note April 2013

CGIAR Research Program on Water, Land and Ecosystems (WLE). 2017.A Framework for Business Model Development for Incentivizing Adoption of Solar Pumps.CGIAR Research Program on Water, Land and Ecosystems (WLE).4p.

Council of Europe. 2008. Report of High-Level Task Force on Social Cohesion: Towards an Active, Fair and Socially Cohesive Europe.

Dalberg. (2019, September). *Solar water Pump outlook 2019: Global trends and market opportunities*. Efficiency for Access Coalition. https://efficiencyforaccess.org/publications/solar-water-pump-outlook-2019-global-trends-and-market-opportunities.

De Guia-Abiad, V. (1993). Borrower transaction costs and credit rationing in rural financial markets: the Philippine case. Developing Economies, 31, 208-208.

Diop, Lamine & Mariama, Diallo & Sidy, Seck & Mateos, Luciano & Nicola, Lamaddalena & Aminata, Sarr & Diatta, Ibrahima & Wane, Yaye & Diallo, Mariama. (2020). TECHNICAL AND ECONOMIC FEASIBILITY OF SOLAR IRRIGATION PUMPING SYSTEM: A REVIEW. 01. 1-22.

FAO. (2015). The economic lives of smallholder farmers. FAO Food and Agriculture Organization of the United Nations, 39. http://www.fao.org/3/i5251e/i5251e.pdf

FAO (2018). The benefits and the risks of solar-powered irrigation - a global overview.

FAO. (2020). Deconstructing the gender gap in rural financial inclusion. https://doi.org/10.4060/cb0569en

Feder, G. (1980). Farm size, risk aversion and the adoption of new technology under uncertainty. Oxford Economic Papers, 32(2), 263–283. https://doi.org/10.1093/oxfordjournals.oep.a041479

Fernando, J. (2021, June 2). *Financial Literacy*. Investopedia. https://www.investopedia.com/terms/f/financial-literacy.asp.

GIZ and FAO. (2018, April). *Solar Powered Irrigation Systems (SPIS) Finance*. SPIS Finance. https://energypedia.info/wiki/SPIS_Finance.

Goubert, A. (2020, January 31). Why and how should Microfinance Institutions provide non-financial services? Microfinanza. https://www.microfinanza.com/why-and-how-should-microfinance-institutions-provide-non-financial-services/.

Hanouch, M. and Rotman, S. (2013). Microfinance and Mobile Banking: Blurring the Lines? CGAP Focus Note 88, January 2012.

Holt, C.A.; Laury, S.K. Risk aversion and incentive effects. Am. Econ. Rev. 2002,92, 1644–1655.

Hossain, M. A., Hassan, M. S., Mottalib, M. A., & Ahmmed, S. (2015). Technical and economic feasibility of solar pump irrigations for eco-friendly environment. Procedia Engineering, 105, 670-678.

Iyer, P.; Bozzella, M.; Hirsch, S.; Meraner, M.; Finger, R. Measuring farmer risk preferences in Europe: A systematic review. J. Agric. Econ. 2020,71, 3–26

Izzi, G., J. Denison and G.J. Veldwisch, eds. 2021. The Farmer-led Irrigation Development Guide: A what, why and how-to for intervention design. Washington, DC: World Bank.

Karanja, J., Wachira, A., & Lyria, R. (2015). Influence of collateral requirements on Sacco's credit accessibility in Imenti North Sub-County, Kenya. *International Journal of Economics, Commerce and Management*, *3*(9).

Kenton, W. (2021, May 19). *Usufruct Definition*. Investopedia. https://www.investopedia.com/terms/u/usufruct.asp.

Kilian, L. (2012, September). Food Security & Staple Crops. *IAEA*.

Kirui, O.K.; Okello, J.J. and Nyikal, R. (2010). Awareness and use of m-banking services in agriculture: The case of smallholder farmers in Kenya By Contributed Paper presented at the Joint 3 rd African Association of Agricultural.

KPMG. (2014). (rep.). *Feasibility analysis for solar agricultural water pumps in India* (pp. 1–28). Retrieved from https://shaktifoundation.in/wp-content/uploads/2014/02/feasibility-analysis-for-solar-High-Res-1.pdf

Kumar, Vikas & Hundal, Bikramjit & Kaur, Kulwinder. (2019). Factors affecting consumer buying behaviour of solar water pumping system. Smart and Sustainable Built Environment. 8. 10.1108/SASBE-10-2018-0052.

Lanao, I. F., & Serres, P. (2009). Microfinance and non-financial services: an impossible marriage? Proparcos Magazine, 6–9. https://fi-compass.eu/sites/default/files/publications/microfinance-and-non-financial-services-an-impossible-marriage.pdf

Linh, T. N., Long, H. T., Chi, L. V., Tam, L. T., & Lebailly, P. (2019). Access to rural credit markets in developing countries, the case of Vietnam: A literature review. *Sustainability*, *11*(5), 1468.

Major Risks for Banks - Overview, Regulations, and Examples. Corporate Finance Institute-CFI. (2020, January 17). https://corporatefinanceinstitute.com/resources/knowledge/finance/major-risks-for-banks/.

Marr, A. (2012). Effectiveness of rural microfinance: What we know and what we need to know. Journal of Agrarian Change, 12(4), 555-563.

Mecha, N. S. (2017). Effect of microfinance on poverty reduction: A critical scrutiny of theoretical literature. *Global Journal of Commerce & Management Perspective*, *6*(3), 16–33. https://doi.org/10.24105/gjcmp.6.3.1702

Mermod, A. Y. (2013). Microfinance. *Encyclopedia of Corporate Social Responsibility*, 1674–1682. https://doi.org/10.1007/978-3-642-28036-8_85

Moll, H. A. (2005). Microfinance policies and rural development: changes and challenges.

Mugenzi, P. (2014). *Access to and utilization of Microcredits by farmers in Rwanda: Case study of Musanze District*. 1–73. http://edepot.wur.nl/300175

Murphy, S. (2012). Changing Perspectives: Small-scale farmers, markets and globalization. In *International Institute for Environment and Development (IIED) and Humanist Institute for Development Cooperation (HIVOS)*.

Nathan, A. J., & Scobell, A. (2020). Off-Grid Solar Market Trends Report 2020. *International Finance Corporation*, *91*(5), 215. https://www.gogla.org/sites/default/files/resource_docs/2018_mtr_full_report_low-res_2018.01.15_final.pdf

Payne, G., & Payne, J. (2004). Key Concepts in Social Research. SAGE Publications, Ltd. https://doi.org/10.4135/9781849209397

Pearce, Douglas. "Financial Services for the Rural Poor." CGAP Donor Brief, no. 15, Washington, D.C.: CGAP, October 2003.

Physik, G. F. (2018). Access to finance for Small holders Farmers latin America. International Finance Corporation, 1–84. www.ifc.org

Polonsky, M. J. (1995). A stakeholder theory approach to designing environmental marketing strategy. Journal of Business & Industrial Marketing, 10(3), 29–46. https://doi.org/10.1108/08858629510096201

Ragui, Mary. (2017). Mobile Banking: A Strategic Approach to Promote Financial Inclusion for Women Entrepreneurs? IOSR Journal of Business and Management. 19. 48-54. 10.9790/487X-1907024854.

RVO, N. E. A. (2018). Developing your Theory of Change. 1–6. https://english.rvo.nl/sites/default/files/2018/11/FBK_theory_of_change_guidelines_0.pdf

Sachs, J. D., W. T. Woo, N. Yoshino, and F. Taghizadeh-Hesary. 2019. Why Is Green Finance Important? ADBI Working Paper 917. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/why-green-finance-important

Schmitter, P., Kibret, K. S., Lefore, N., & Barron, J. (2018). Suitability mapping framework for solar photovoltaic pumps for smallholder farmers in sub-Saharan Africa. *Applied Geography*, *94*(October 2017), 41–57. https://doi.org/10.1016/j.apgeog.2018.02.008

Schnetzer, J. and Pluschke, L. 2017.Solar-Powered Irrigation Systems: A clean-energy, low-emission option for irrigation development and modernization. Food and Agriculture Organization (FAO). Rome, Italy.

Segal, T. (2020, November 19). *How can you play the float?* Investopedia. https://www.investopedia.com/terms/f/float.asp#:~:text=What%20Is%20the%20Float%3F,as%20a%20check%20is%20deposited.

Sulewski, P., Was, A., Kobus, P., Pogodzinska, K., Szymanska, M., & Sosulski, T. (2020). Farmers' attitudes towards risk-an empirical study from poland. Agronomy, 10(10 October), 1–21. https://doi.org/10.3390/agronomy10101555

Takeshima, Hiroyuki & Adeoti, Adetola & Salau, Sheu & Headquarters, Ifpri. (2010). Measuring the Effect of Transaction Costs for Investment in Irrigation Pumps: Application of Unobserved Stochastic Threshold Model to the Case of Nigeria.

Talaat, M. (2018). Using SROI as a tool to quantify non-financial risks within credit risk management in banks. University of Twente.

Thapa, G., & Gaiha, R. (2014). Smallholder farming in Asia and the Pacific: challenges and opportunities. *New Directions for Smallholder Agriculture*, 69–114. https://doi.org/10.1093/acprof:oso/9780199689347.003.0004

The SEEP Network. (2015). A practical guide to monitoring & evaluation for microfinance associations. https://seepnetwork.org/files/galleries/1500_m-and-e-ENG.pdf

Ullah, R.; Shivakoti, G.P.; Ali, G. Factors effecting farmers' risk attitude and risk perceptions: The case ofKhyber Pakhtunkhwa, Pakistan. Int. J. Disaster Risk Reduct. 2015,13, 151–157.

Wang, Y., & Zhi, Q. (2016). The Role of Green Finance in Environmental Protection: Two Aspects of Market Mechanism and Policies. *Energy Procedia*, *104*, 311–316. https://doi.org/10.1016/j.egypro.2016.12.053

Weijermars, B., (2014). MICROFINANCE: THE ROAD TO DEVELOPMENT? Wageningen University.

Widhiyanto, I., Nuryartono, N., Harianto, H., & Siregar, H. (2018). The Analysis of Farmers' Financial Literacy and its' Impact on Microcredit Accessibility with Interest Subsidy on Agricultural Sector. *International Journal of Economics and Financial Issues*, *8*(3), 148.

World Bank. 2003. Reaching the Rural Poor: A Renewed Strategy for Rural Development. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/14084 License: CC BY

World Commission on Environment and Development. (1987). Our common future (Brundtland report). Oxford: Oxford University Press.

Appendix

Interview Guide for Solar Irrigation Experts

Questions about Agriculture, Irrigation, and farmers:

- How does the FAO define "smallholder farmers"?
- How do you think Solar Irrigation can act towards solving the meta problem of food insecurity, especially in small farms?
- Despite the fact that solar irrigation technology is now mature, this kind of irrigation is still not fully adopted in a large scale by smallholder farmers. What are the main barriers that impede the diffusion of solar irrigation in small farms?
- Are farmers educated about the latest, modern agricultural technologies, especially about solar irrigation? If yes, are there available training/programmes provided from FAO? If no, what capacity building programmes do you think would further enhance the adoption rate?
- Where do you think is the bottle neck in the solar irrigation value chain? (Supply side, Distribution Side, Consumption side)
- How can governments support the adoption of more solar water pumps in small farms?

Questions about rural finance:

- What are the financial barriers that limit the adoption of modern agricultural technologies, such as solar irrigation?
    - Looking into the barriers from the farmers' perspective
    - Looking into the barriers from Solar Irrigation Technology's perspective
    - Looking into the barriers from the financial institutions' perspective
- Do you think financing services would increase the adoption of solar-powered irrigation by smallholder farmers?
- If yes, what kind of financial services do you think would fit the farmers and their own perceptions?

Interview Guide for Financial Experts

Questions about farmers' accessibility to finance

- What are the financial barriers that limit the adoption of modern agricultural technologies, such as solar irrigation?
    - Looking into the barriers from the farmers' perspective
    - Looking into the barriers from Solar Irrigation Technology's perspective
    - Looking into the barriers from the financial institutions' perspective
- Do you think financing services would increase the adoption of solar-powered irrigation by smallholder farmers?
- If yes, what kind of financial services do you think would fit the farmers and their own perceptions?
- What are the barriers that restrict farmers from using microfinance services?
- What are the main risks that MFIs face when dealing with farmers?
- Do men and women working in the agricultural sector have equal opportunities to access credit? If no, what are the reasons that you think this discrimination comes from?

Specific questions about Microfinance Institutions (MFIs):

- What are the reasons that make MFIs to be involved in the rural sector?
    - Is it mission driven, or market driven?
    - Is it to expand to rural market due to the competitiveness and saturation of urban market?
    - Is it due to portfolio diversification?
    - Another reason
- Use of credit officers with agricultural backgrounds is generally considered a significant success factor for agricultural lending. Based on your experience, which option do you prefer, hiring loan officers with prior agricultural lending experience and a degree in a related field (i.e., agriculture, agribusiness, rural development or hiring a loan officer with a more generalist background, complemented by specialized agricultural training, to be able to serve both agricultural and non-agricultural clients?
- On what criteria do MFIs segment farmers?
- What are the typical requirements needed from farmers to obtain credit from MFIs?
- What is the maximum amount of money that farmers are allowed to obtain from MFIs?
- What is the typical interest rate charged on loans given to farmers?

- How long is it allowed for farmers to pay back the loan?
- How is money collected back from farmers to MFIs?
- What are the main challenges that MFIs face when they recover loans from farmers?
- Are there any governmental policies that govern the operations of MFIs? And what policies do you think can further enhance the positioning of MFIs within the agricultural sector?

Informed Consent Form

Informed Consent form for MSc. MEEM thesis

Semi-structured interview on "Microfinance for the Adoption of Modern Agricultural Technologies – Focus on Solar Irrigation".

Below are the ethical considerations, that the research participant agrees on, before conducting the interview:

- Research participant is aware of the research aims and activities before conducting the interview.
- Research participant can withdraw from the interview at any time without explanation/justification.
- Research Participant is offered to review what is written in the thesis, if requested.
- Research participant agrees that he/she will be cited in this research.

Signature of the research participant:

I declare to fully adhere to all of the above.

Name: Omar Marzouk